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ABSTRACT

O'CONNOR, JAMES ROBERT. A Climatology of Regional Ozone: Meteorological Effects on Ozone Exceedences in the Southeast United States. (Under the direction of Dr. Viney P. Aneja.)

A statistical analysis of ozone (O_3) concentrations and meteorological parameters was performed to determine the effect of meteorological changes on ambient O_3 concentrations in the urban and semi-urban environment on a regional basis in the Southeast United States. The correlation between average daily maximum O_3 concentration and various meteorological variables was analyzed on a monthly basis from April through October during 1980-1994. Positive correlation was found between O_3 concentration and temperature and dewpoint temperature depression, while negative correlation was found between O_3 concentration and relative humidity and the minimum Pasquill Stability Index. The correlations were strongest during the summer months, particularly June, July, and August. High pressure stagnation was found to be positively correlated with O_3 concentrations, although not at a statistically significant level. Regional analysis indicates that the *location* of areas of high pressure stagnation may play an important role in the resultant ambient concentrations of O_3 throughout the region. Analysis of long term O_3 concentration trends indicates increasing trends during the 1980s and decreasing trends during the 1990s. Trends for meteorological parameters that demonstrate positive (negative) correlation with O_3 increase (decrease) during the 1980s and decrease (increase) during the 1990s, however causal relationship between these trends and those for O_3 cannot be determined based on this analysis. A regional model was developed to forecast ozone concentration based on the previous day's ozone concentration and meteorological parameters. An exponential model performed best, as compared to linear and quadratic models. The most efficient model fit ($R^2 = 0.51$) was an exponential model that included parameters for the previous day's ozone concentration, maximum temperature, average relative humidity, dewpoint temperature, and minimum Pasquill Stability Index.

A CLIMATOLOGY OF REGIONAL OZONE:

METEOROLOGICAL EFFECTS ON OZONE EXCEEDENCES IN THE SOUTHEAST UNITED STATES.

by

JAMES ROBERT O'CONNOR

A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the Degree of
Master of Science

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BIOGRAPHY

James R. O'Connor was born in Kingston, NY on July 07, 1969. He grew up in Lyndonville, NY, a small town in the western portion of the state. He attended L. A. Webber Jr./Sr. High School and graduated second in his class in 1987, earning an Air Force Reserve Officer Training Corps (ROTC) scholarship to the university of his choice.

During the fall of 1987, he enrolled at the University of Notre Dame. While at Notre Dame, Jim was active in campus ministry and ROTC, and also worked as a grader for the Mathematics Department. In May, 1991, he received his Bachelor of Science degree in mathematics, with a concentration in business administration, and was commissioned a Second Lieutenant in the United States Air Force.

In June of 1991, he began the Air Force Basic Meteorology Program (BMP) at The Pennsylvania State University, funded through the Air Force Institute of Technology's Civilian Institution Program (AFIT/CI). While living in Pennsylvania, he married Katherine Maryann Pellek, a fellow Notre Dame alumna. In June of 1992, he was awarded a Bachelor of Science in meteorology from Penn State.

Upon completion of BMP, Jim was stationed at Andrews Air Force Base in Camp Springs, MD. While at Andrews, he served as the Presidential Weather Support Officer and wing weather officer for the 89th Airlift Wing.

In early 1994, Jim was accepted into the AFIT/CI program again to attend graduate school. During the summer of 1994, he moved to Raleigh, NC and began attending North Carolina State University, studying toward a Master's degree in Atmospheric Sciences.

Jim is currently a Captain in the U.S. Air Force. Upon completion of his graduate school program, he will be assigned to the 88th Weather Flight at Wright-Patterson AFB, Dayton, OH, where he will work in the research and development and acquisition of weapon systems.

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Funding for the research in this project has been provided by the State of North Carolina Department of Environment, Health, and Natural Resources (DEHNR) under contract #J6021: Trends, Seasonal Variations and Analysis of Ozone in Raleigh, NC. The author wishes to thank Mr. George Murray and Dr. Wayne Cornelius for their assistance throughout the project. The student is sponsored by the US Air Force, Air Force Institute of Technology (AFIT) at Wright-Patterson Air Force Base in Dayton, OH. The author wishes to thank the the Air Force for funding this education, and in particular Major Tom Neu, for providing guidance along the way on how to best suit the Air Force's needs.

The author would like to acknowledge several people for assistance in the completion of this thesis. Master Sergeant Jim Pinyerd at the Air Force Combat Climatology Center (AFCCC) at Scott AFB, IL helped by offering a career's worth of advice regarding which meteorological parameters should be analyzed; then retrieving all of the meteorological data from AFCCC's database. In addition, the high pressure stagnation maps presented in Appendix 1 were painstakingly generated by him. Heather Bowden and Brenda Batts in the Marine, Earth, and Atmospheric Science Department's main office scanned in and retouched the maps depicting the site locations in Chapter Two. My committee members, Dr. Arya and Dr. Dickey, and in particular my advisor Dr. Aneja, have worked very hard to keep me on track and help me muddle my way through performing graduate level research. Their guidance and insightful suggestions have taught me how different scientific disciplines interact to formulate new ideas and test hypotheses, leading to the advancement of science. The entire air quality group, but in particular T.C. Moore, Paul Roelle, Regi Oommen, and Mita Das, have provided hours of fruitful discussion that helped to formulate ideas throughout the process of attending graduate school and focusing in on this research issue.

Finally, without the continuous love and encouragement of my family, I would not have been able to complete the last two hectic years of graduate education. My parents and siblings have always encouraged me and guided me along the way to give me the confidence I need to continue reaching for higher goals. The curiosity they have expressed about my work has given me the chance to solidify much of what I have learned by explaining it to others who are not directly involved with meteorological and air quality issues on a daily basis. Most importantly however, my wife Kathy has been with me day in and day out through the last two years of difficult exams, long study sessions, late dinners, short evenings, and unpredictable moodiness. She has tolerated proof-reading of, and discussions about, more air quality issues than she even knew existed. For Kathy's continually accepting, and even better, understanding, my needs throughout the past two years, I dedicate this thesis to her.

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CHAPTER 1. INTRODUCTION

1.1 BACKGROUND

Ozone is an atmospheric oxidant in a class of pollutants known as *photochemical* oxidants, since photochemical reactions (chemical reactions involving sunlight energy) are required for atmospheric ozone formation. In the stratosphere (that portion of the atmosphere from about 20 kilometers to 50 kilometers above the earth's surface), ozone absorbs harmful short wavelength (< ~ 300nm) incoming solar radiation, thus protecting the earth's inhabitants (both plants and animals) from this destructive ultraviolet radiation. Evidence of an "ozone hole" in the stratosphere over Antarctica has been highlighted in recent history, causing the general population to believe that more ozone is needed to alleviate air quality issues plaguing cities today. However, photochemical oxidants in the troposphere (from the earth's surface up to about 20 kilometers) such as ozone may lead to damage to plants, may be responsible for the decline of forests both in the Southeast United States and in Europe (Woodman and Cowling, 1987; Schutt and Cowling, 1985) and may be responsible for most of the crop damage caused by air pollution in the United States (Heck, et al., 1982; Logan, 1985). In humans, the effects of elevated ozone exposure include changes in lung capacity, flow resistance and bronchial efficiency (Logan, 1985; Lippmann, 1989). It has been hypothesized that the isolated short term extreme peaks in ozone concentration may be more harmful than an equivalent dose (dose = concentration x time of exposure) of elevated ozone concentration over longer timeframes (Heck, et. al., 1966; U. S. Environmental Protection Agency, 1986; Lefohn and Pinkerton, 1988). In addition, tropospheric ozone is a greenhouse gas and thus leads to global warming by trapping infrared radiation emitted by the earth's surface (National Research Council, 1991). Moreover, the control of ozone in urban environments is a nagging problem (National Resource Council, 1991). It is these underlying effects of ozone pollution that fuel the scientific community's desire to better understand the chemical and physical relationships that drive the formation and potential accumulation of ozone and other photochemical oxidants in the lower troposphere. By better understanding these

relationships, atmospheric scientists are able to develop models to predict how the air quality of the lower troposphere will react to external influences such as changes in pollutant emission rates or meteorology, which drive the chemical reaction rates, thus ultimately affecting ambient concentrations of photochemical oxidants in the atmosphere.

1.2 OZONE FORMATION

Ozone is not emitted directly into the troposphere by any source (Penkett, 1991). Instead, it is formed via photochemical reaction of other compounds referred to as "primary pollutants" (i.e., pollutants that are emitted directly). Thus, by definition, O_3 is referred to as a "secondary pollutant". The primary pollutants that lead to the production of O_3 include NO_X (= $NO + NO_2$) and volatile organic compounds (VOCs) or hydrocarbons, along with photochemical energy (i.e., sunlight). That is, O_3 is formed by (Logan, 1985; Penkett, 1991),

$$O(^3P) + O_2 + M \longrightarrow O_3 + M \qquad \text{Reaction 1}$$

where M represents an inert compound, following the photolysis of nitrogen dioxide (NO_2):

$$NO_2 \xrightarrow{h\nu} O(^3P) + NO \qquad \text{Reaction 2}$$

and may be removed by reaction with nitric oxide (NO):

$$NO + O_3 \longrightarrow NO_2 + O_2 \qquad \text{Reaction 3}$$

Reactions 1, 2, and 3 are called the photostationary state and lead to no net accumulation of O_3. However, a variety of complex organic peroxy radicals and hydroperoxy radicals (represented here as RO_2 and HO_2, respectively) will disrupt the cyclical nature of (1), (2), and (3) as these radicals will preferentially react with the NO formed from (2) via reactions such as (Logan, 1985; Penkett, 1991):

$$RO_2 + NO \longrightarrow NO_2 + RO \qquad \text{Reaction 4}$$

$$HO_2 + NO \longrightarrow NO_2 + OH \qquad \text{Reaction 5}$$

Nitrogen Dioxide (NO_2) formed via (4) and (5) will photodissociate via (2), from which (1) will procede. Thus, the net result is the accumulation of ozone. One sample mechanism for the

formation of ozone as a result of peroxy and hydroperoxy radicals scavaging available NO is given by Warneck (1988):

$OH + CO + O_2 \longrightarrow HO_2 + CO_2$	Reaction 6
$HO_2 + NO \longrightarrow NO_2 + OH$	Reaction 7
$NO_2 \xrightarrow{h\nu} NO + O(^3P)$	Reaction 8
$O(^3P) + O_2 + M \longrightarrow O_3 + M$	Reaction 9 (same as 1, above)
Net reaction: $CO + 2O_2 \longrightarrow CO_2 + O_3$	Reaction 10

Among other sources, both NO_X and hydrocarbons are products of burning fossil fuels, and are thus present in the emissions from automobiles, power generation facilities, and biomass burning (Penkett, 1991). As a result, these emissions from these anthropogenic activities may lead to the long-term interannual increase in O_3 concentration observed at remote sites (Liu, et al., 1987). Hydrocarbons and NO_X are also present in biogenic emissions (Penkett, 1991): hydrocarbons are emitted from plants; NO_X is emitted from soils, particularly from managed (fertilized) soils. Anywhere from 11% to 25% of NO_X is emitted from agricultural fields (Sullivan, 1996), while as much as 50% of hydrocarbons emitted are from plants and trees in rural areas in the Southeast US (Chaimeides, et al., 1988). It is well known (Chameides, et al., 1988; Kleinman, et al., 1994; Kelly and Gunst, 1990; Liu, et al., 1987; Logan, 1981; Logan, 1985; Mathur, et al., 1994; Rao, et al., 1996; Sillman, et al., 1990; Trainer, et al., 1987) that the concentration of O_3 measured at any particular time and space is sensitive to the amount of NO_X and hydrocarbons present and their relative ratios to each other, thus different regions may require different control strategies (NO_X control vs. hydrocarbons control) in order to effectively reduce ambient O_3 concentrations. However, although it has been shown that the concentrations of both NO_X and hydrocarbons have decreased with respect to time in recent years (Logan, 1985), ambient concentrations of O_3 have failed to fall below the NAAQS and in fact have increased in several areas (Logan, 1985; Walker, 1985; Oltmans and Komhyr, 1986; Rao, et al., 1996; Volz and Kley, 1988). In fact, middle

tropospheric O_3 concentrations in Europe and North America increaed at a rate of ~1% per year from 1969-1981 (Angell and Korshover, 1983). It is for these reasons that in 1991 the National Research Council (NRC, 1991) called O_3 one of the "most pervasive and stubborn of environmental problems" facing the country. In spite of a quarter century of regulations and control programs designed to bring the O_3 problem under control, a solution to the problem continues to be both perplexing and evasive.

1.3 EFFECT OF METEOROLOGY

Meteorology plays an important role in the rate of formation of O_3 (Logan, 1989; National Resource Council, 1991). Since photochemistry (i.e., sunlight, designated below as hν) initiates a chemical reaction chain of events that leads to O_3 formation as noted earlier,

$NO_2 \xrightarrow{h\nu} NO + O(^3P)$ Reaction 2

$NO + RO_2 \longrightarrow NO_2 + RO$ Reaction 4

$O(^3P) + O_2 + M \longrightarrow O_3 + M$ Reaction 9

clear skies, increased solar radiation, and thus warmer temperatures lead to increased rates of formation of O_3 (Warneck 1988; Logan 1981; 1985; 1989). Note that the above chain reaction occurs readily as long as the ambient concentration for NO_X is about 1 ppm or higher, the concentration above which peroxy radicals (byproducts of reactions involving hydrocarbons, denoted above as RO_2) will preferentially react with NO (Logan, 1989). It is also well recognized that, along with temperature, relative humidity and wind speed also affect the rate of O_3 formation in the lower troposphere (McNider, 1993; Trainer, et al., 1987; Vukovich, 1994). It has also been suggested that the rates of O_3 formation are closely associated with high pressure, and in particular persistant stagnating high pressure systems (Aneja, et. al., 1990; 1991; 1994; Korshover, 1976; Wolff, et. al., 1977; 1979; 1980; 1982; 1987; Vukovich, et. al., 1977; Vukovich, 1994; Wight, et. al., 1978). Note that since meteorology plays such a significant role in affecting ambient ozone

concentrations, it is difficult to determine whether changes in ambient concentrations result from policy driven control on precursor emissions or from fluctuations in meteorological conditions.

1.4 MOTIVATION

The desire to understand the chemical relationships' interaction with meteorology has driven the motivation to perform this research. In particular, since it is hypothesized that extreme peaks of ozone concentration lead to the most damage, this study focuses on attempting to gain an understanding of what combination of external influences lead to ozone exceedences in atmospheric air quality, as defined by the U.S. Environmental Protection Agency (EPA). The EPA has designated National Ambient Air Quality Standards (NAAQS) under the Clean Air Act of 1970 as a measure of overall air quality to protect human health and environmental welfare with respect to six "criteria pollutants": Lead (Pb), Sulfur Dioxide (SO_2), Carbon Monoxide (CO), PM10 (Particulate Matter of less than 10 microns), NO_X (Nitric Oxide (NO) and Nitrogen Dioxide (NO_2)), and Ozone (O_3). For ozone, the NAAQS is based on the one hour average concentration; for which the standard is 0.12 parts per million by volume (ppmv). There are two measures of exceedence: one, if the second highest daily maximum hourly average of O_3 exceeds the standard on any given day, or two, if there are three or more days in three consecutive years for which the daily maximum hourly average is above the standard. If either of these conditions are met, the site is designated as "nonattainment" for O_3. Note however, that each time the concentration is above 0.12 ppmv, the entire period of time is recorded as only one potential exceedence, regardless of the length of time that the concentration is in excess of the standard. Above 0.12 ppmv, there exist five degrees of nonattainment ranging from “marginal” to exteme” nonattainment, as shown in Table 1.1. As it is written, the NAAQS for O_3 allows a site to measure a concentration above the standard for one hour for two consecutive years without being penalized. However, for the purposes of this study, any day for which the maximum hourly average of O_3 was above 0.12 ppmv was considered an exceedence day.

1.5 OBJECTIVES

In this work, nine sites in five different metropolitan statistical areas (MSAs) throughout the Southeast United States were analyzed for O_3 and meteorological trends during a fifteen year climatology (1980-1994). Urban and semi-urban sites are studied since it is hypothesized that urban pollution plays an important role in leading to the elevated O_3 concentrations in nonurban troposphere throughout the United States and Europe (Logan, 1981; Logan, 1985). In addition, ozone's relatively long winter lifetime, combined with an abundance of O_3 precursors from anthropogenic sources, may lead to hemispheric transport of O_3, especially in winter (Liu et al., 1987). However, ozone's relatively short lifetime in summer results in the ambient O_3 concentration being controlled by transport on a regional level. Means and interyear variability are presented along with trends in an attempt to discern the meteorological parameters' effect on ambient O_3 concentration. Climatological means for these variables are presented to quantify levels for the meteorological parameters which may lead to O_3 exceedence. The effect of stagnating high pressure systems is studied using Korshover's (1976) definition of high pressure stagnation, as well as our own surface observation-based stagnation parameter. In addition, the effect of instability leading to O_3 exceedences is examined, using the Pasquill Stability Index as a measure of stability. Finally, a model is developed to forecast O_3 concentration based on meteorological parameters and persistence from the previous day's maximum O_3 concentration.

Table 1.1. Classifications of nonattainment, as designated by the U.S. Environmental Protection Agency (USEPA).

Classification of Nonattainment	Ozone Concentration (ppmv)
Marginal	0.121 - 0.138
Moderate	0.138 - 0.160
Serious	0.160 - 0.180
Severe	0.180 - 0.280
Extreme	>0.280

CHAPTER 2. DATA RETRIEVAL

2.1 STUDY PERIOD

As stated in Chapter One, ambient concentrations of ozone are highly dependent on meteorology; specifically, the amount of incoming solar energy and thus temperature. Because ozone formation in the lower troposphere is photochemically dependent, elevated ozone levels and ozone exceedences are not likely to occur during late fall, winter, and early spring. It is generally accepted that the most photochemically active time of the year, during which elevated ozone levels or ozone exceedences are likely to occur, is from April 01 until October 31. For this reason, data was retrieved only for this time period of each year for the analysis. The analysis in this document is based on fifteen years, from 1980 to 1994. Fifteen years were selected to provide chemical and physical climatology for the region, and also to provide a wide variety of meteorological conditions and the potential to study several high ozone episodes.

2.2 SITE SELECTION

Nine sites in five different Metropolitan Statistical Areas (MSAs) were chosen throughout the Southeast United States to be representative of the urban and semi-urban areas in the region. The analysis was performed on urban areas since they are the areas that are most often in noncompliance with the NAAQS for ozone; more than 60 cities in the United States remained in violation of the NAAQS in 1988 and more than 40% of these cities were in the south (Chameides, et al., 1988). The Southeast US was chosen because summertime ozone in the south is among the highest in the United States by region (Chameides and Cowling, 1995). Two characteristics make the Southeast US relatively unique when developing an ozone abatement strategy. First, the southeast has a stagnant and hot summer climatology that restricts the mixing of pollutants

upward, thus resulting in ozone accumulation near the ground (Vukovich, 1977; 1994; Korshover, 1976; Chameides and Cowling, 1995). Second, dense vegetation (60-70% of the region is covered with forest), when coupled with the hot summer climatology, results in anomalously high emissions of isoprene, terpenes, and other natural hydrocarbons, particularly from forests (Chameides and Cowling, 1995; Lamb, et. al., 1987; Penkett, 1991; Trainer, et al., 1987, 1991). Consequently, sites in MSAs that have been designated non-attainment areas in the Southeast US were selected based on completeness of available ozone data. The goal was to find two sites in each of five MSAs: Atlanta, GA; Greensboro, NC; Charlotte, NC; Raleigh-Durham, NC; and Nashville, TN, with >85% data capture efficiency. Data capture efficiency was calculated by summing up the total number of days that had data available for the study period, then dividing by the total number of days possible in the study period (3210 days in all cases). However, missing data due to periodic reallocation of sites during the fifteen year study period left only one site that met the 85% data capture efficiency criterion for each Raleigh-Durham, NC and Greensboro, NC MSAs. Therefore, a third site was selected in Charlotte, NC, since one of our primary goals is to assist in refining the State Implementation Plan (SIP) for North Carolina. Table 2.1 summarizes geographical data for the sites selected along with data capture efficiency statistics and land usage classification; Figure 2.1 is a regional map depicting the site locations.

The Environmental Protection Agency assigns a 9 digit identification code for each of its monitoring sites; the first two digits identify the state, the next three digits identify the county, and the last four identify the specific site within the county. For simplicity when referring to sites, a reduced form of identification standard is presented for the data in this analysis. A six or seven character code is assigned to each site, for which the first three characters are letters corresponding to the airport identifier from which the meteorological data was retrieved for the site (also identifies which MSA the site is in), followed by three digits corresponding to the county just as the EPA

does, which may be followed by another letter if there is more than one site used in this study in that particular county (only true for Charlotte). The site location information and land use designations given for each site in the following paragraphs were obtained from the EPA's Aerometric Information Retrieval System (EPA-AIRS) database in Research Triangle Park, NC.

Site ATL089 (EPA #130890002; see Figure 2.2.) is located at 33.691°N and 84.273°W; about 14.5 kilometers (km) southeast of the center of Atlanta, GA in DeKalb County, on the DeKalb County Community College Campus, on land designated for commercial use. Meteorological data used in the analysis for this site was taken from The Hartsfield Atlanta International Airport, about 16 km west-southwest from the ozone monitoring site.

Site ATL247 (EPA #132470001; see Figure 2.2.) is located at 33.586°N and 84.067°W; about 32 km southeast of the center of Atlanta, GA in Rockdale County at Conyers Monastery, on land designated for agricultural use. Meteorological data analyzed for this site was taken from The Hartsfield Atlanta International Airport, about 30.5 km west-northwest from the site.

Site BNA037 (EPA #470370011; see Figure 2.3.) is located at 36.205°N and 86.745°W; about 5.5 km north-northwest of downtown Nashville, TN along the Cumberland River in Davidson County, on residential land. Meteorological data used in the analysis was retrieved at the Nashville International Airport, about 15.2 km southeast of the site.

Site BNA165 (EPA #471650007; see Figure 2.3.) is located at 36.298°N and 86.653°W; in Sumner County about 19 km northeast of downtown Nashville, TN. Meteorological data used in the analysis for BNA165 was collected at the Nashville International Airport, about 21 km south of the site. The site is located at the Old Hickory Dam in Rockland Recreation Area and is designated as industrial land.

Site CLT119H (EPA #371190034; see Figure 2.4.) is located at 35.247°N and 80.764°W; about 8 km east of the center of Charlotte, NC in Mecklenburg County. It is located at the corner

of Plaza Road and Lakedell Drive, and land use is designated residential. Meteorological data was recorded at the Charlotte-Douglas International Airport, about 16 km west-southwest of the site.

Site CLT119I (EPA #371191005; see Figure 2.4.) is located at 35.113°N and 80.919°W; about 14.5 km southwest of downtown Charlotte, NC, also in Mecklenburg County on land that used industrially. Meteorological data was collected at the Charlotte-Douglas International Airport, about 10.5 km north of the site.

Site CLT119J (EPA #371191009; see Figure 2.4.) is located at 35.348°N and 80.693°W; on NC Highway 29 North at the border of Mecklenburg and Cabarrus Counties. Located in Mecklenburg County, this site is about 19 km northeast of the center of Charlotte, NC on land designated for agricultural use. Meteorological data used in the analysis for this site was collected at the Charlotte-Douglas International Airport, about 26.5 km southwest of the site.

Site GSO081 (EPA #370810011; see Figure 2.5.) is located at 36.113°N and 79.704°W; in Keely Park on Keely Road in Guilford County. The site is about 9.5 km northeast of Greensboro, NC. The land use designation is residential. Meteorological data used the analysis for this site was collected at the Piedmont Triad International Airport, located in Greensboro about 21.5 km west-southwest of the ozone monitoring site.

Site RDU183 (EPA #371832001; see Figure 2.6.) is located at 35.971°N and 78.491°W; about 24 km northeast of the center of Raleigh, NC in Wake County. The site is located at the Wake Forest water treatment plant on NC Highway 98 on land that is designated for agricultural use. Meteorological data used in the analysis for this site was collected at the Raleigh-Durham International Airport, about 24 km southwest of the site.

2.3 OZONE DATA

Hourly averaged ozone data were downloaded from the Environmental Protection Agency's Aerometric Information Retrieval System (EPA-AIRS) database using an ethernet link to the North Carolina State University Marine, Earth, and Atmospheric Science Department's VAX. The data files were then further reduced from hourly observations to daily observations in three categories: 1.) The average ozone concentration from 10:00 am to 4:00 pm Eastern Standard Time (EST), 2.) The daily maximum concentration, and 3.) The time of daily maximum concentration. The daily average from 10:00 am to 4:00 pm EST was chosen to best pinpoint the most atmospheric photochemically active part of each day. When computing the daily average concentration, the 11:00 a.m. EST observation was the first observation used since it represents the average concentration between 10:00 a.m. and 11:00 a.m., and the 4:00 p.m. observation was the last used; it represents the average concentration between 3:00 p.m. and 4:00 p.m. Missing data was recorded as such (interpolated values were not inserted); therefore some of the daily averages are based on fewer than six data points. In addition, all exceedences (hourly averaged concentrations > 0.12 ppmv) were noted along with the hour at which each of the exceedences occurred. Table 2.2 summarizes all exceedences for each site by month.

The hour of the maximum concentration was used to further cleanse the data. Since ozone formation in the lower troposphere is dependent upon photochemical reactions, it was assumed that on days when the hour of maximum ozone concentration was recorded either before 9:00 am or after 9:00 pm there was a problem with data missing during most if not all of the twelve hours between those times. Therefore, those days were eliminated from further analysis in the study. Performing this cleansing of the database did not result in the loss of any days whose maximum daily concentration exceeded the ozone standard.

2.4 METEOROLOGICAL DATA

Meteorological data were extracted from databases at the Air Force Combat Climatology Center (AFCCC) at Scott Air Force Base, IL. Since meteorological data was not available for precisely the same locations as each ozone monitoring site, meteorological data was taken from the nearest available reporting station for each MSA. The World Meteorological Organization (WMO) identifiers used to retrieve data for Atlanta, Raleigh, Charlotte, Greensboro, and Nashville were 722190, 723060, 723140, 723170, and 723270, respectively. For each of the five MSAs listed in Section 2.2, hourly observations were used to derive the daily maximum temperature and calculate daily averages (10:00 am to 4:00 pm EST) for temperature, wind speed, mean sea level pressure, and relative humidity. Daily averages were calculated using seven hourly observations (instead of six as was used to calculate the ozone daily averages, see Section 2.3) since the observation taken on each hour is representative of conditions only at that time, not an hourly average of the preceding hour. From the relative humidity averages, a dewpoint temperature average was calculated using the relationships:

$$e_s = 6.112 \exp\left(\frac{17.67T}{T+243.5}\right) \quad \text{Equation 2.1}$$

$$e = 6.112 \exp\left(\frac{17.67T_d}{T_d+243.5}\right) \quad \text{Equation 2.2}$$

$$RH = \frac{e}{e_s} \quad \text{Equation 2.3}$$

Where e_s = saturation vapor pressure (mb)

e = vapor pressure at dewpoint temperature (mb)

T = ambient air temperature (°C)

T_d = dewpoint temperature (°C)

RH = relative humidity (fraction)

Then inserting Eqs (2.1) and (2.2) into Eqn (2.3) and solving for dewpoint, the conversion was derived:

$$T_d = 243.5\left(\frac{17.67T-(T+243.5)\ln(RH)}{(17.67)(243.5)+(T+243.5)\ln(RH)}\right) \qquad \text{Equation 2.4}$$

Following calculation of the daily average dewpoint temperature, the daily average dewpoint temperature depression was calculated by simply subtracting the daily average dewpoint temperature from the daily average temperature. As such, larger (smaller) dewpoint temperature depression values indicate more dry (moist) atmospheric conditions.

In addition to these basic parameters, the Pasquill Stability Index and a stagnation parameter were also calculated, as described in the following sections.

2.4.1 PASQUILL STABILITY INDEX

Pasquill (1961; see also Turner, 1964) defined a stability classification to characterize dispersion of air pollutants near the earth's surface. The Pasquill Stability Index assumes that during daytime stability near the ground is dependent primarily upon net solar radiation and wind speed. Using the Pasquill stability scheme, net solar radiation is estimated based on solar altitude and modified for existing conditions of total cloud cover and ceiling height. The most instability occurs with the lightest wind and the most incoming solar radiation, as displayed in Table 2.3, where letters earlier (later) in the alphabet indicate more instability (stability). Pasquill originally developed the Pasquill Stability Index using letters; Turner (1964) redefined the classes using numeric categories for computational purposes using dispersion models, according to Table 2.4.

Using the Turner scheme of determining the Pasquill Stability Index, stability class during daylight hours is determined according to the following process (Turner, 1964):

A. Determine the net radiation index according to:
   1. If the total cloud cover is 10/10 (overcast) and the ceiling is less than 7000 feet (~2135 meters), use the net radiation index equal to 0.
   2. During other than sky condition overcast with ceiling less than 7000 feet (~2135 meters),
      a. Determine the insolation class number as a function of solar altitude using Table 2.5.
      b. If total cloud cover is ≤ 5/10, let the net radiation index equal the insolation class number.
      c. If cloud cover > 5/10, modify the insolation class number following these steps:
         1. Ceiling <7000 ft (~2135 m), subtract 2.
         2. 7000 ft (~2135 m) ≤ ceiling < 16000 ft (~4875 m), subtract 1.
         3. Total cloud cover equal 10/10 (with ceiling ≥ 7000 ft (~2135 m)), subtract 1.
         4. If insolation class number has not been modified in 1, 2, or 3 above, assume modified class number equal to insolation class number.
         5. If modified insolation class number is less than 1, let it equal 1.

B. Use Table 2.6 and determine the Pasquill Stability Index corresponding to the determined net radiation index and the wind speed for the timeframe.

The Pasquill Stability Index was calculated for each hour of the day from the hourly observations as recorded at AFCCC, according to the classes in Table 2.3. However, only daytime hours (10:00 am until 4:00 pm EST) are used here to calculate an average (numeric) Pasquill Index and minimum (numeric) Pasquill Index since atmospheric photochemical activity is expected to be at a maximum during this timeframe. The minimum Pasquill Index was considered to serve as a measure of instability during the least stable portion of the day, as an attempt to pinpoint the greatest amount of photochemical activity for each day.

2.4.2 STAGNATION PARAMETER

Korshover (1976) presented a 40 year climatology of high pressure stagnation events in a National Oceanographic and Atmospheric Administration (NOAA) Technical Memorandum, using

pressure gradient values as a basis of determining areas of stagnation. Briefly, Korshover considered an anticyclone to be stagnant when, using National Weather Service daily synoptic sea level analysis maps,

1. the geostrophic wind (wind not affected by effects of friction with the earth's surface) remained less that 15 knots (~7.7 m/s),
2. there were no frontal zones in areas of apparent stagnation, and
3. there was no precipitation,

for a period of four consecutive days. As a method of automating Korshover's analysis technique and applying it to hourly synoptic observations, we have defined high pressure stagnation using the following criteria:

1. Surface wind speed < 8 knots (~4.1 m/s). Korshover (1976) used the ratio of 0.5 for surface wind to geostrophic wind.
2. Sky cover < 5/8ths coverage. (i.e., there should not be a ceiling.)
3. Lack of stratiform precipitation. Short-lived (<2 hours duration) passing thunderstorms were allowed since afternoon convective activity is likely, even during high pressure stagnation events, in the southeast. (McNider, 1993)

Two occurrences violating each of criterion 1 and 2 were allowed per day to account for the possibility of a passing thunderstorm during an otherwise "stagnant" day during which significant photochemical activity is expected. The stagnation parameter is defined on a daily basis, and from the daily classification of stagnation two other variables were derived, as described here. Stagnation "count" is defined simply as the number of consecutive days meeting the stagnation criteria, as defined above. Finally, in order to be able to compare directly with Korshover's analysis, a stagnation "event" parameter was also defined. Since Korshover only considered stagnation events to be four consecutive days meeting stagnation criteria, the stagnation "event"

parameter described here is based on meeting four consecutive days of daily stagnation criteria. Stagnation "event" is derived by dividing stagnation count by four, then discarding any values less than one. Defined as such, stagnation event equals one only when the criteria for daily stagnation are met four days in a row. In cases when the daily stagnation criteria are met for more than four days consecutively, the stagnation event parameter may increase above one. That is, stagnation event equals 1.25 after five consecutive days meet the daily stagnation criteria, 1.50 after six consecutive days meet the daily stagnation criteria, et cetera. Each of these statgnation parameters were calculated for each day in the data set obtained from AFCCC for each of the five MSAs used in the study. In addition, the days meeting the stagnation parameter criteria were tabulated for the entire Southeast US region (over 130 sites) and isoplethed by year. The annual high pressure stagnation plots (see Appendix 1) will be compared to each other and to a climatological (1980-1994) high pressure stagnation plot in Section 3.3.

Table 2.1. Site Characteristics

Site Code Monitor ID	MSA (Metropolitan Statistical Area)	Lat. (°N)	Long. (°W)	Elev. (m)	Land Use Designation	Data Days	Data Capture Efficiency (%)
ATL089 **130890002**	Atlanta, GA	33.691	84.273	305	commercial	2948	93.0
ATL247 **132470001**	Atlanta, GA	33.586	84.067	219	agricultural	2845	88.6
BNA037 **470370011**	Nashville, TN	36.205	86.745	165	residential	2857	89.0
BNA165 **471650007**	Nashville, TN	36.298	86.653	143	industrial	2861	89.1
CLT119H **371190034**	Charlotte, NC	35.247	80.764	239	residential	2863	89.2
CLT119I **371191005**	Charlotte, NC	35.113	80.919	195	industrial	2925	91.1
CLT119J **371191009**	Charlotte, NC	35.348	80.693	255	agricultural	3016	94.0
GSO081 **370810011**	Greensboro, NC	36.113	79.704	229	residential	2894	90.2
RDU183 **371832001**	Raleigh, NC	35.971	78.491	87	agricultural	2736	85.2

Table 2.2. Summary of Number of Exceedences For Each Site By Month (in days per month). "--" indicates missing data for that month.

Year	Month	ATL089	ATL247	BNA037	BNA165	CLT119H	CLT119I	CLT119J	GSO081	RDU183
1980	4	0	--	0	--	--	--	0	0	0
	5	0	--	0	0	--	--	0	0	1
	6	0	--	0	0	--	0	0	0	0
	7	2	0	2	1	0	0	5	0	2
	8	3	0	2	2	0	2	3	0	1
	9	2	0	0	0	0	0	0	0	0
	10	0	0	0	0	0	0	0	0	0
1981	4	0	0	0	0	0	0	0	0	0
	5	0	0	--	0	0	0	0	0	0
	6	2	3	0	0	1	1	0	0	0
	7	2	4	0	0	0	1	1	0	0
	8	0	0	0	0	0	0	0	0	0
	9	0	1	0	2	1	0	0	0	0
	10	0	0	0	0	0	0	0	0	0
1982	4	0	0	0	0	0	0	0	0	0
	5	0	0	0	0	1	0	0	0	0
	6	1	1	0	1	0	0	0	0	0
	7	2	0	0	0	0	0	0	0	0
	8	0	0	0	0	0	1	0	0	0
	9	0	0	0	0	0	0	0	0	0
	10	0	0	0	0	0	0	0	--	--
1983	4	0	0	0	0	0	0	0	0	0
	5	1	0	0	0	1	0	0	0	0
	6	1	1	0	0	0	1	0	0	0
	7	8	7	0	0	0	1	2	0	0
	8	7	8	0	0	1	1	3	0	2
	9	0	0	1	1	0	0	0	0	0
	10	0	0	0	0	0	0	0	0	0
1984	4	0	0	0	0	0	0	0	0	0
	5	0	0	0	0	0	0	0	0	0
	6	2	4	0	4	0	0	0	0	0
	7	0	1	0	2	3	0	0	0	0
	8	1	1	0	0	0	0	1	0	0
	9	0	1	0	0	1	0	0	0	0
	10	0	0	0	0	0	0	0	0	0

Table 2.2., continued.

Year	Month	ATL089	ATL247	BNA037	BNA165	CLT119H	CLT119I	CLT119J	GSO081	RDU183
1985	**4**	0	0	0	0	0	0	0	0	0
	5	1	0	0	0	0	0	0	0	0
	6	1	4	0	1	0	0	0	0	0
	7	0	3	0	2	1	0	0	0	0
	8	0	1	0	0	0	0	0	0	0
	9	0	0	0	0	0	0	0	0	0
	10	--	0	0	0	0	0	0	--	0
1986	**4**	1	0	0	0	0	0	0	0	0
	5	0	0	0	0	0	0	0	0	0
	6	3	3	0	1	0	1	0	1	0
	7	8	2	0	1	2	5	1	1	0
	8	1	3	0	1	2	0	0	0	0
	9	0	0	0	0	0	0	0	0	0
	10	0	0	0	0	0	0	0	0	0
1987	**4**	0	0	0	0	0	0	0	0	0
	5	0	0	0	0	0	0	0	0	0
	6	3	4	0	1	0	0	0	0	0
	7	6	2	0	0	1	5	0	0	1
	8	6	5	0	2	1	1	2	0	1
	9	0	1	--	0	0	0	0	0	0
	10	0	0	0	0	0	0	0	0	0
1988	**4**	0	0	0	0	0	0	0	0	0
	5	0	0	1	2	0	1	0	0	0
	6	10	2	2	5	4	4	6	2	7
	7	2	3	0	3	3	3	4	5	2
	8	0	1	0	3	1	1	1	3	2
	9	0	1	0	0	0	0	1	0	0
	10	0	0	0	0	0	0	0	0	0
1989	**4**	0	0	0	0	0	0	0	0	0
	5	0	0	0	0	0	0	0	0	0
	6	0	1	0	1	1	0	1	0	0
	7	1	0	0	1	0	0	0	0	0
	8	0	1	0	0	1	0	1	0	0
	9	0	0	0	0	0	0	0	0	0
	10	0	0	0	0	0	0	0	0	0

Table 2.2., continued.

Year	Month	ATL089	ATL247	BNA037	BNA165	CLT119H	CLT119I	CLT119J	GSO081	RDU183
1990	4	0	0	0	0	0	0	0	0	0
	5	0	0	0	0	0	0	0	0	0
	6	4	4	0	1	0	0	0	1	0
	7	1	0	0	4	0	0	1	0	0
	8	1	5	0	2	0	1	1	0	0
	9	1	4	0	0	0	0	0	0	0
	10	0	0	0	0	0	0	0	0	0
1991	4	0	0	0	0	0	0	0	0	0
	5	0	0	0	0	0	0	0	0	0
	6	0	0	0	0	1	0	1	0	0
	7	2	1	0	0	0	1	0	0	0
	8	0	0	0	1	0	0	0	0	0
	9	2	1	0	0	0	0	0	0	0
	10	0	0	0	0	0	0	0	0	0
1992	4	0	0	0	0	0	0	0	0	0
	5	0	0	0	1	0	0	0	0	0
	6	0	0	0	0	0	0	0	0	0
	7	0	1	0	0	0	0	0	0	0
	8	2	2	0	0	0	0	0	0	0
	9	0	0	0	0	0	0	0	0	0
	10	0	0	0	0	0	0	0	0	0
1993	4	0	0	0	0	0	0	0	0	0
	5	0	1	0	0	0	0	0	0	0
	6	0	1	0	0	0	0	1	0	0
	7	5	4	0	1	1	1	1	2	0
	8	1	2	0	1	1	1	0	0	0
	9	1	2	0	0	0	0	0	0	0
	10	0	0	0	0	0	0	0	0	0
1994	4	0	0	0	0	0	0	0	0	--
	5	0	1	0	0	0	0	0	0	--
	6	0	0	0	2	0	0	0	0	--
	7	1	0	0	1	0	0	0	0	--
	8	0	1	0	0	0	0	0	0	--
	9	0	0	0	0	0	0	0	0	--
	10	0	0	0	0	0	0	0	0	--

Table 2.3. Pasquill Stability Index classifications
Assumes surface wind speed (anemometer at 10 meters).

wind speed (m/s)	**insolation, daytime**			**cloudiness, nighttime**	
	strong	**moderate**	**slight**	**$\geq 4/8$**	**$\leq 3/8$**
<2	A	A-B	B	--	--
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
>6	C	D	D	D	D

Table 2.4. Numeric equivalent to Pasquill's alphabetic classification scheme (as defined by Turner, 1964).

Pasquill classification	**Definition**	**Numeric Equivalent, P**
A	extremely unstable	$0 \leq P < 2$
B	moderately unstable	$2 \leq P < 3$
C	slightly unstable	$3 \leq P < 4$
D	neutral	$4 \leq P < 5$
E	slightly stable	$5 \leq P < 6$
F	moderately stable	$6 \leq P < 7$
G	extremely stable	$7 \leq P < 8$

Table 2.5. Insolation as a function of solar altitude (Turner, 1964).

Solar Altitude, a	Insolation	Insolation class number
$60° < a$	strong	4
$35° < a \leq 60°$	moderate	3
$15° < a \leq 35°$	slight	2
$a \leq 15°$	weak	1

Table 2.6. Stability class as a function of net radiation index and wind speed (Turner, 1964). Note: 1 knot = 1 nautical mile/hr = 0.515 m/s.

Wind Speed (knots)	Net Radiation Index						
	4	3	2	1	0	-1	-2
0,1	1	1	2	3	4	6	7
2,3	1	2	2	3	4	6	7
4,5	1	2	3	4	4	5	6
6	2	2	3	4	4	5	6
7	2	2	3	4	4	4	5
8,9	2	3	3	4	4	4	5
10	3	3	4	4	4	4	5
11	3	3	4	4	4	4	4
≥12	3	4	4	4	4	4	4

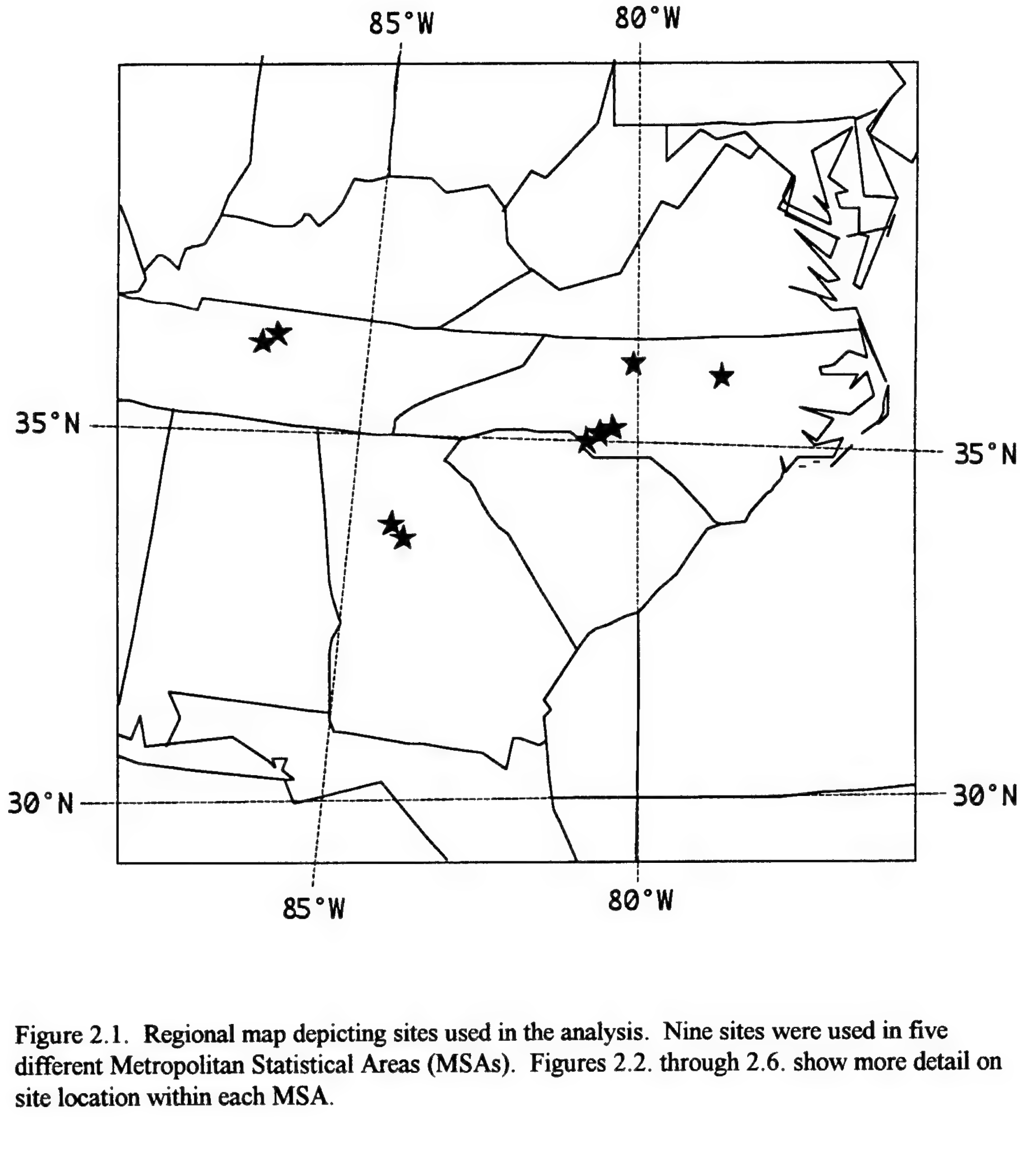


Figure 2.1. Regional map depicting sites used in the analysis. Nine sites were used in five different Metropolitan Statistical Areas (MSAs). Figures 2.2. through 2.6. show more detail on site location within each MSA.

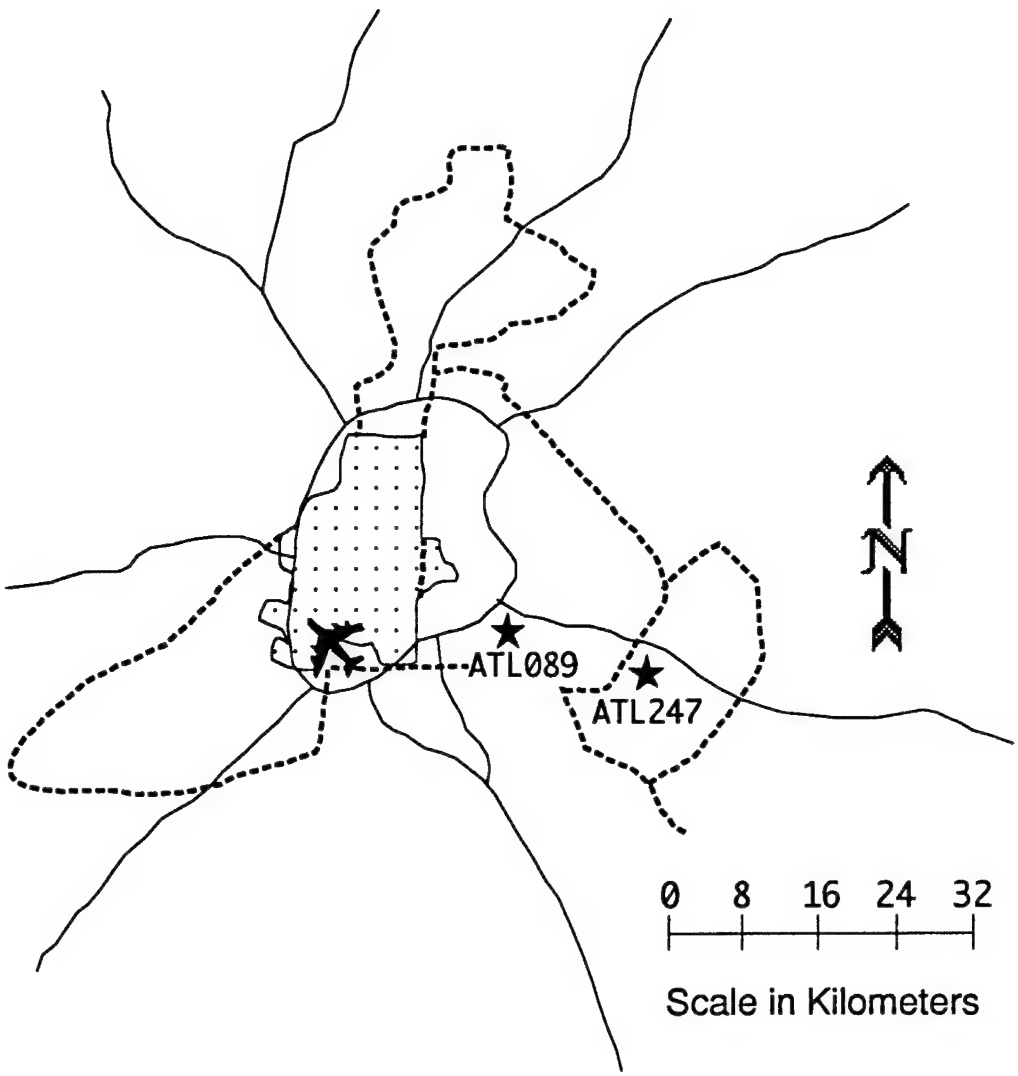


Figure 2.2. Map of Atlanta, GA Metropolitan Statistical Area (MSA) indicating location of US Environmental Protection Agency (USEPA) ozone monitoring sites used (stars) and World Meteorological Organization (WMO) weather station (airplane). The urban core is shaded with dots, dashed lines indicate county borders, thick solid lines represent major highways.

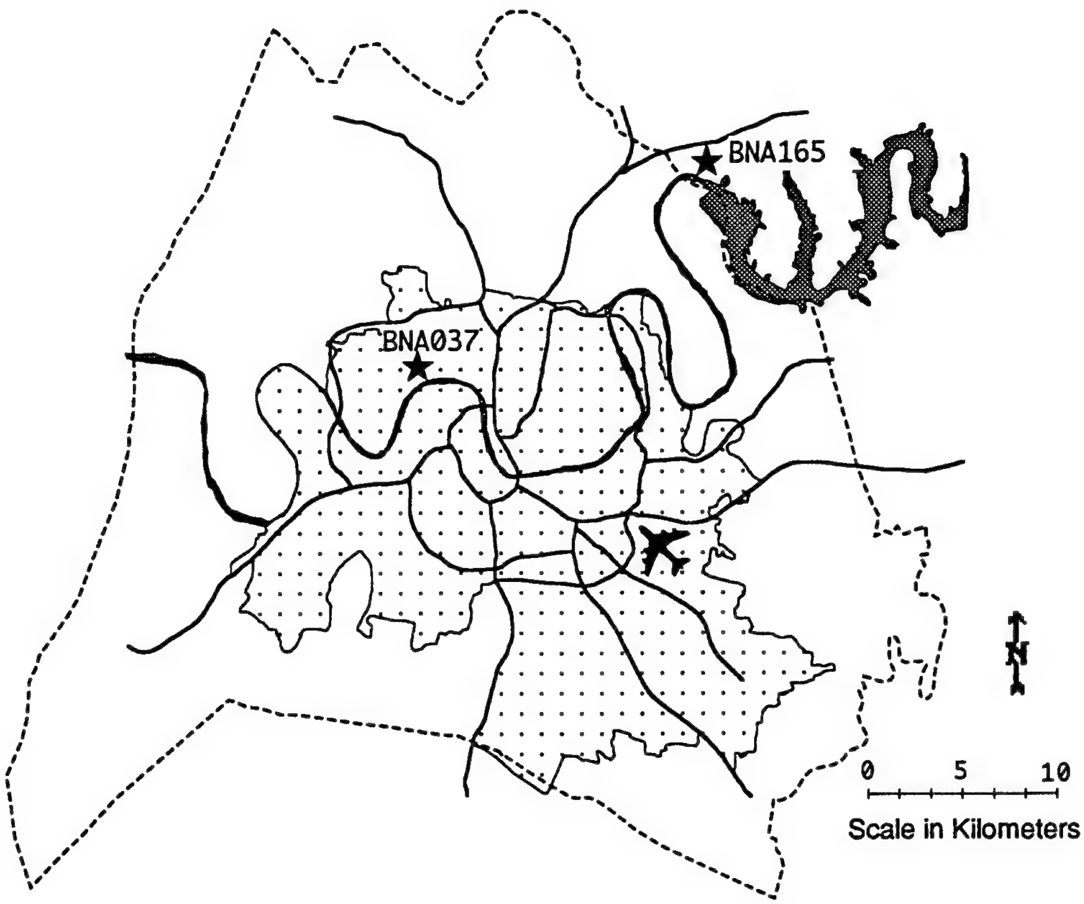


Figure 2.3. Map of Nashville, TN Metropolitan Statistical Area (MSA) indicating location of US Environmental Protection Agency (USEPA) ozone monitoring sites used (stars) and World Meteorological Organization (WMO) weather station (airplane). The urban core is shaded with dots, dashed lines indicate county borders, thick solid lines represent major highways. Dark shading represents major bodies of water.

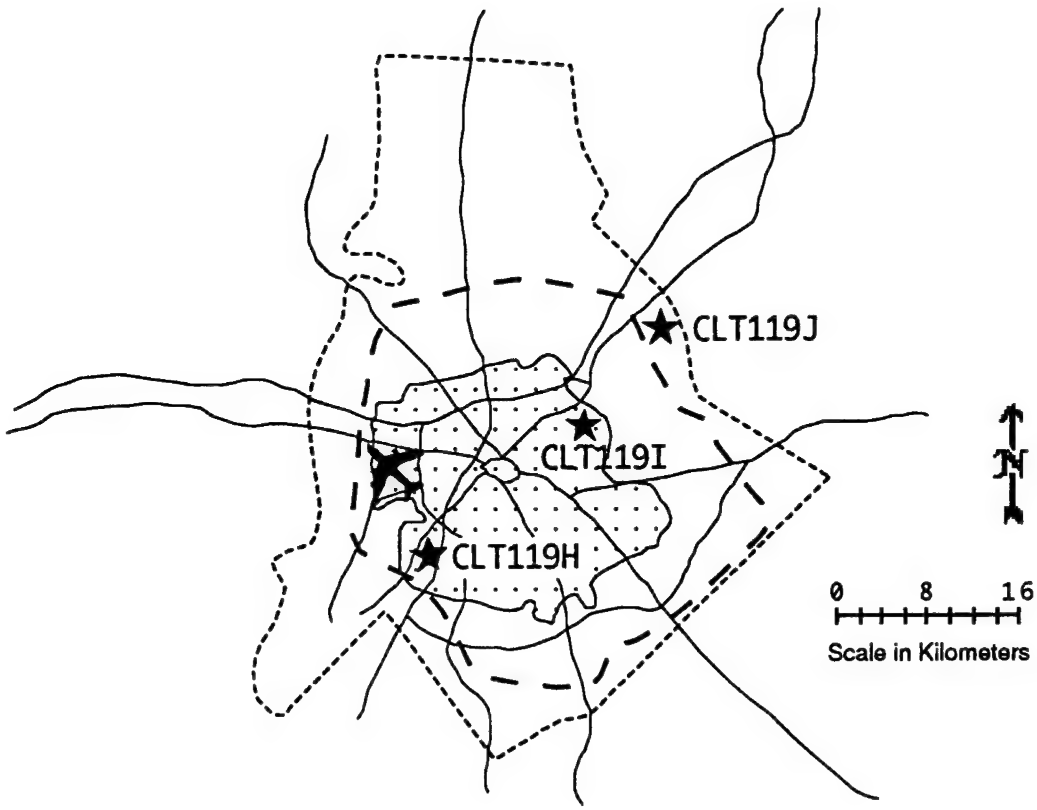


Figure 2.4. Map of Charlotte,NC Metropolitan Statistical Area (MSA) indicating location of US Environmental Protection Agency (USEPA) ozone monitoring the sites used (stars) and World Meteorological Organization (WMO) weather station (airplane). The urban core is shaded with dots, dashed lines indicate county borders, thick solid lines represent major highways.

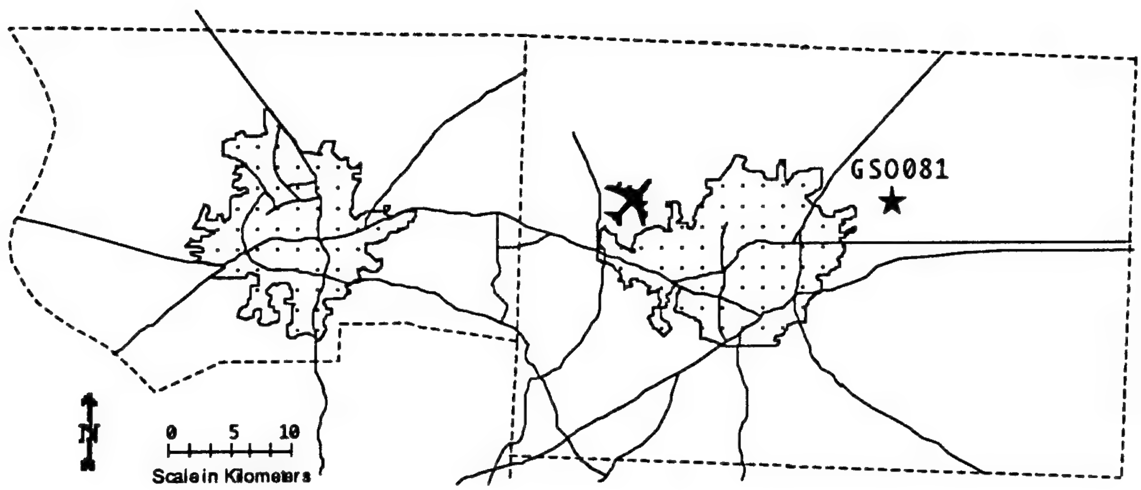


Figure 2.5. Map of the Greensboro - Winston Salem, NC Metropolitan Statistical Area (MSA) indicating location of US Environmental Protection Agency (USEPA) ozone monitoring site used (star) and World Meteorological Organization (WMO) weather station (airplane). The urban cores are shaded with dots (Greensboro is on the right, Winston-Salem is on the left). Dashed lines indicate county borders, thick solid lines represent major highways.

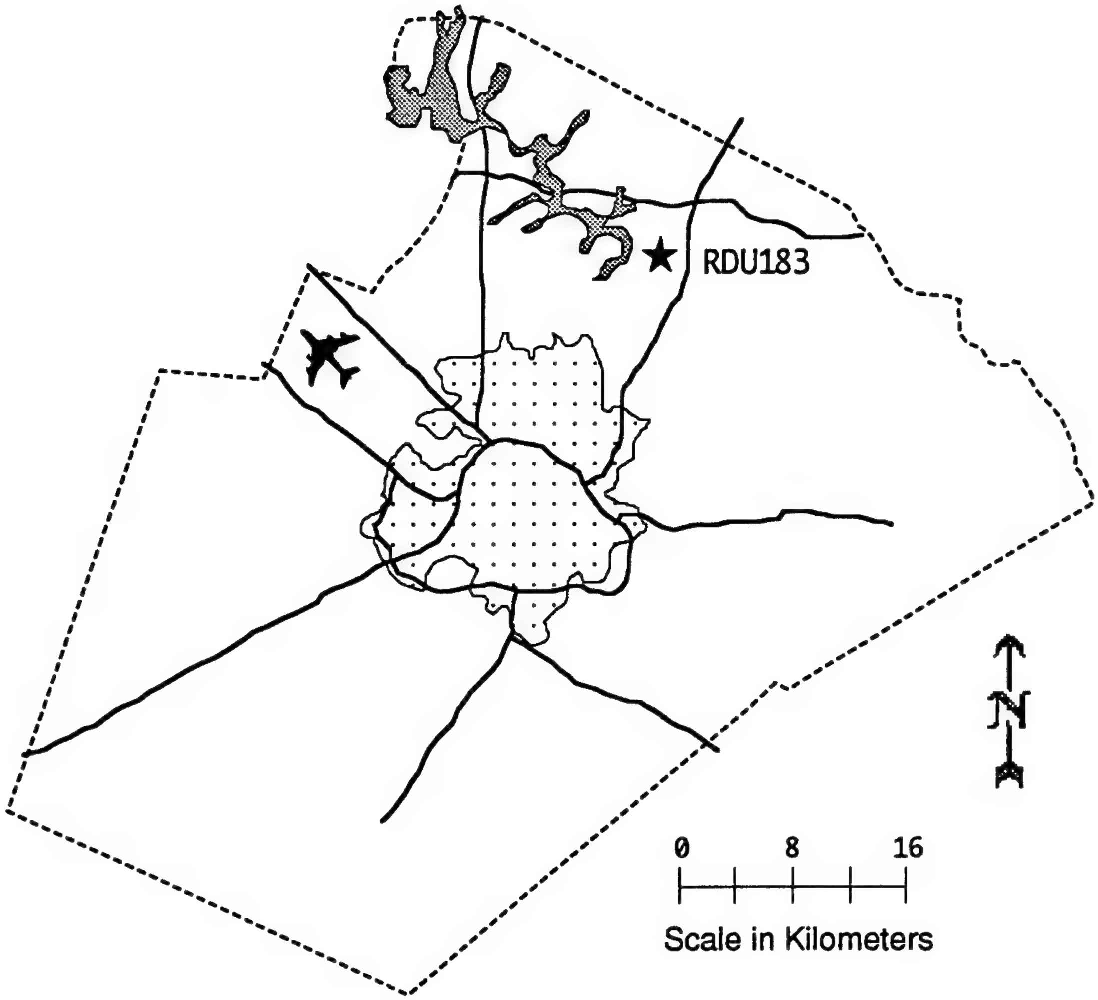


Figure 2.6. Map of Raleigh,NC Metropolitan Statistical Area (MSA) indicating location of US Environmental Protection Agency (USEPA) ozone monitoring the site used (star) and World Meteorological Organization (WMO) weather station (airplane). The urban core is shaded with dots, dashed lines indicate county borders, thick solid lines represent major highways. Dark shading represents major bodies of water.

CHAPTER 3. CLIMATOLOGICAL ANALYSIS

3.1 ANALYSIS OF EXCEEDENCE DAYS

To begin the analysis, the data set was segregated according to whether or not the O_3 standard (0.120 ppmv) was exceeded for a given day. Note that if more than one site exceeded on the same day, that day was counted more than once to account for all site-days of O_3 exceedence. Across all sites and during all months (April - October) there were 389 site-days of exceedence. June, July, and August accounted for over 90% of the exceedence site-days, with 108, 142, and 102 site-days each, respectively. The remaining months had significantly fewer exceedence site-days as shown in Figure 3.1. Clearly, the three month ozone season of June, July, and August is the most problematic period of the year during which O_3 concentrations are most likely to exceed the NAAQS. This is due to the fact that these months have the warmest and driest conditions, and therefore increased photochemical activity, which leads to increased O_3 concentrations. Since meteorological conditions vary between months, the exceedences were analyzed first by month, then for the three month ozone season, to determine if statistical significance could be attached to the difference between averages of meteorological variables on exceedence site-days compared to averages for all site-days in the data set. Since April had only one exceedence site-day and October did not have any exceedence site-days, the monthly analysis of exceedence site-days for these months is not presented.

In general, warmer and drier conditions during all months lead to O_3 exceedences. Tables 3.1 through 3.6 summarize exceedence site-days statistics for various meteorological parameters in comparison to statistics for all days. Values in the tables printed in boldface type highlight averages for exceedence days which are statistically significantly different from the overall average for that parameter for the period covered on that table.

The tables show that for all months the daily maximum temperature is always statistically significantly higher during an exceedence day. On exceedence days, the three month "ozone season" climatological average of daily maximum temperature on exceedence days was 93.8±4.0°, compared to the average daily maximum temperature on all days in the study during the same season of 87.8±5.5°. In addition, the average wind speed is statistically significantly lower for all months during exceedence days. During the three month ozone season, average wind speed was 5.0±1.5 knots, statistically lower than the average wind speed for all days during the same season of 5.4±1.9 knots.

Ozone exceedence days are also more likely to occur on relatively dry days. The average relative humidity is statistically significantly lower on exceedence days for all months except May. In May, O_3 exceedence days have, on average, lower relative humidities, but not at a statistically significant level. Throughout the three month ozone season, the average relative humidity on exceedence days is 68.8±10.1%, statistically lower than the average for all days during the season of 77.7±10.1%. Another measure of atmospheric moisture near the surface of the earth, dewpoint temperature depression, indicates similar results. Statistically significantly larger dewpoint temperature depression values are found on O_3 exceedence days for all months except May. As with relative humidity, May's dewpoint temperature depression value is larger (i.e., drier conditions) on exceedence days, but not at a statistically significant level. During the three month ozone season, the average dewpoint temperature depression on exceedence days was 11.3±4.4°, statistically significantly higher than the average dewpoint temperature depression on all days of 7.6±3.9°. The actual dewpoint temperature is not as good an indicator of moisture in the atmosphere since a given dewpoint temperature can have a wide range of relative humidities, over which O_3 production will vary widely. Consequently, there was not a clear pattern to indicate whether or not higher or lower dewpoint temperatures potentially lead to O_3 exceedences; some

months indicated that lower dewpoint temperatures, while other months indicated that higher dewpoint temperatures, lead to O_3 exceedences. The statistical significance was marginal at best; thus dewpoint temperature was not found to be a strong indicator of O_3 exceedence.

Average mean sea level pressure is not statistically significantly higher on exceedence days, contrary to our expectations. Only for the month of May is the average pressure statistically significantly higher on exceedence days, and even then it is only by a marginal amount (1018.2±2.3 mb, compared to the average for all days of 1016.5±4.3 mb). In August, the mean sea level pressure was lower on average for exceedence days (1016.3±3.0 mb compared to the average over all days of 1017.5±3.2 mb). For the three month ozone season, the climatological average of mean sea level pressure on exceedence days was 1018.3±2.9 mb as compared to 1018.9±4.2 mb on all days included in the data set. Consequently, on a climatological basis, higher than average mean sea level pressure values fail to be an indicator of O_3 exceedence days.

The minimum Pasquill Index on exceedence days was statistically significantly lower than that for all days for every month in the study. The average Pasquill Index on exceedence days was statistically significantly higher during most months. However, the rejection statistic for the minimum Pasquill Index was nearly triple that for the average Pasquill Index for all months except September. The minimum Pasquill Index has a larger range throughout the climatological period than the average Pasquill Index does, thus resulting in larger differences in values for the parameter on exceedence days versus values for the parameter throughout the data period. Considering the three month ozone season, on exceedence days the average minimum Pasquill Index was 2.34±0.54, while that for average Pasquill Index was 4.85±0.04. For all days throughout the three month ozone season, the parameters had average values of 2.96±0.79 and 4.68±0.50, respectively.

The stagnation and count parameters are slightly higher on O_3 exceedence days than when they are averaged across all days. For all months, they both demonstrate statistical significance,

but it is not very strong. The event parameter does not demonstrate statistically higher values on exceedence days for any of the months, likely due to the few number of cases that meet the stagnation event criteria. During the three month ozone season, the stagnation, count, and event parameters average values on exceedence days are 0.33±0.47, 0.55±0.97, and 0.02±0.15, respectively. Averaged over all of the days in the three month season, the values of the parameters is 0.15±0.36, 0.24±0.69, and 0.00±0.11. Although the averages for the stagnation and count parameters demonstrate statistically significantly higher numbers for these parameters on exceedence days, they appear to be a weak indicator toward predicting O_3 exceedence days.

3.2. TEMPORAL VARIATIONS

3.2.1. STATISTICAL DETERMINATION OF THE OPTIMUM OZONE SEASON

Determination of the optimum ozone season was performed in two steps. First, all nine of the sites were considered as one regional data set and ozone's dependency on meteorology was analyzed for each month in the study, described in Section 3.2.1.1 below. Next, the months were combined to examine the effect of extending the possible ozone season from one optimum month to all seven months considered as potentially high O_3 concentration months in the study (April - October). This second phase of determining the ozone season is described in Section 3.2.1.2.

3.2.1.1. REGIONAL ANALYSIS BY MONTH

The complete data set was divided into 105 (seven months x fifteen years) smaller data subsets, each one representing the regional data for one month of one year throughout the study period. In some cases, data gaps present in the complete data set became more pronounced when the data set was broken down into smaller subsets since there were cases in which nearly an entire month of data was missing for a given site. Consequently, each of these 105 data subsets was

scrutinized to ensure that it contained at least 80% of the data site-days possible to exist for the period. That is, for each April, June, and September the maximum possible data site-days was 270 (nine sites x 30 days), while for each May, July, August, and October the maximum possible was 279 (nine sites x 31 days) data site-days. Elimination of those data subsets that had less than 80% data capture efficiency resulted in the loss of 9 of the 105 data subsets, resulting in 96 data subsets with >80% data capture efficiency as shown in Table 3.7.

Regional monthly means for maximum daily O_3 were computed for each month during each year of the study. From these monthly means, climatological regional monthly means for maximum daily O_3 were computed for each calendar month in the study, reducing the data set to only seven means (one for each month, April through October). The climatological means for each month are given in Table 3.8. Then, these climatological monthly means were subtracted from each of the 105 regionally averaged means for each month, resulting in annual deviations from the climatological means for each month. A time series plot of the maximum O_3 deviations by month throughout the period of study is shown in Figure 3.2. Positive (negative) deviations indicate that those months had higher (lower) than the climatological average daily maximum O_3 concentration for that month, compared to other years in the study.

Using the same method as that described above to compute the 96 regional monthly means and climatological regional monthly means for maximum O_3, regional monthly means and climatological regional monthly means for each month were also computed for each of the meteorological parameters listed in Chapter 2.

Finally, correlation coefficients were calculated between the 96 regional monthly means for maximum daily O_3 and the 96 regional monthly means for each of the meteorological parameters, to provide a quantitative estimate of the association between the two data sets, similar to an analysis performed by Vukovich (1994). The Pearson correlation coefficients (r - values)

calculated between the O_3 means and the meteorological means are presented in Table 3.9. Note that no more than fifteen (one for each year in the study, less years deleted due to data capture efficiency falling below 80%) pairs (one each of O_3 variable and meteorological variable) of numbers are represented in each "r-value" in the table. In order to be statistically significant at the 95% confidence level with n=15, $|r| > 0.515$; these statistically significant Pearson correlation coefficients are highlighted with boldface type in Table 3.9.

Many researchers (Korshover, 1976; Vukovich, 1994; Warmbt, 1979; Wolff, et al., 1977) have noted the correlation between higher temperatures and higher ambient O_3 concentrations. The correlation between daily maximum temperature and daily maximum O_3 for this data set is very strong during June, July and August, while the correlation is much lower during the other months. During June, July, and August, daily maximum temperature averages of 86.4±5.2°, 89.4±5.3°, and 87.5±5.4°, respectively, resulted in Pearson correlation coefficients between O_3 and daily maximum temperature of r=0.68, r=0.83, and r=0.94, respectively. Meteorological conditions during these months produce the greatest amount of photochemical activity in the region, which results in more O_3 formation. The other months also demonstrated a positive correlation between O_3 and temperature (r=0.17 to r=0.53), although the correlations were not nearly as strong. The daily average temperature does not correlate as strongly with maximum O_3 concentration as the daily maximum temperature does. Only during July and August (r=0.66 and r=0.91, respectively) was ozone's correlation with daily average temperature statistically significant for this data. The correlation coefficients during the other months (r= -0.11 to r=0.32) show that the parameters are only weakly related at best.

Only for the month of September did average wind speed display significant inverse correlation (r= -0.63) with O_3, contrary to other findings (Chu and Doll, 1991; Vukovich, 1994) that occurrences of high O_3 are generally associated with low wind speed. The other months

generally displayed inverse correlation between average wind speed and O_3, although not at a statistically significant level (range of correlation coefficients was r= -0.32 to r=0.12).

Relatively dry conditions for a given month, compared to the same month in other years, are well correlated with higher ambient O_3 concentrations. During June, July, and August, relative humidity displayed very significant inverse correlation (r= -0.85, r= -0.85, r= -0.90, respectively) while dewpoint temperature depression displayed very significant positive correlation during the same months (correlation coefficients of r=0.87, r=0.85, r=0.92, respectively). The climatological average for relative humidity during June, July and August was 75.3±10.9%, 78.0±10.0%, and 79.7±8.8%, respectively. Therefore if the annual average for relative humidity was below these values for one of these months in any particular year, then higher O_3 was likely to occur during that month for that year. Similarly, the climatological average for dewpoint temperature depression during June, July, and August was 8.5±4.3°, 7.6±4.0°, and 6.8±3.3°, respectively; if the average dewpoint temperature depression for one of these months in a particular year was greater than these values, then higher O_3 would be likely to occur during that month of that year. The other months analyzed also showed similar correlations, but not as strongly. The correlation coefficients between O_3 and relative humidity for the remaining months ranged from r= -0.53 to -0.39, while the correlation coefficients between O_3 and dewpoint temperature depression for the remaining months ranged from r=0.43 to r=0.56. As was discussed earlier in Section 3.1, the actual dewpoint temperature is not a good indicator of the moisture in the atmosphere because a given dewpoint can have a large range of relative humidities, depending on the ambient air temperature. Only one month (August; r=0.61) demonstrated statistically significant correlation between dewpoint temperature and O_3. The remaining months' correlation coefficients between dewpoint temperature and O_3 ranged from r= -0.50 to r=0.02, thus not demonstrating significant correlation.

Stability is also significantly correlated with occurrences of high O_3. Lindsay and Chameides (1988) and Chu and Doll (1991) point out that high O_3 events occur when convection is suppressed. The minimum Pasquill Index demonstrates strong negative correlation (r= -0.88 to r= -0.59) for all months in the study, indicating that instability resulting from strong solar radiation and low wind speed is climatologically correlated with increased O_3. However, the average Pasquill Index (from 10:00 am to 4:00 p.m. EST each day) is significantly positively correlated with O_3 during April, May, and July (correlation coefficients of r=0.63, r=0.79, r=0.79, respectively), and moderately positively correlated with O_3 (r=0.34 to r=0.50) during the remaining months of the study. The seemingly contradictory correlations arising from considering two different interpretations of the Pasquill stability index could indicate that a short time of moderate instability can lead to elevated O_3 levels while extended periods of instability are likely to result in thunderstorms which would in turn wash out the precursors to O_3 before it (O_3) can be formed. In addition, extended periods of instability may tend to ventilate the lower troposphere due to larger mixing heights, resulting in lower concentrations near the surface. McNider (1993) noted a peculiarity similar to ours: that maximum surface O_3 concentrations were highest near an old frontal boundary in an area of convective instability. He measured relatively high O_3 in Atlanta coincident with regional scale deep convective mixing, generally thought to be destructive of high O_3 concentrations at the surface. Other researchers (Logan, 1989; Lindsay and Chameides, 1988; Vukovich, 1994) note that elevated O_3 levels are most often found on the back side of weak, slow moving, persistent high pressure systems; summertime convective activity in the Southeast US is often embedded in weak high pressure systems along an old frontal boundary.

Research has shown that high O_3 episodes are associated with persistent high pressure systems (Chu and Doll, 1991; Lindsay and Chameides, 1988; Logan, 1989; Vukovich, 1994; Wolff and Lioy, 1980). However, average mean sea level pressure does not show significant

correlation with O_3 for this data. Only during the months of June and October did the average mean sea level pressure demonstrate strong positive correlation with O_3, and only during October was the correlation statistically significant (r=0.45 and r=0.70, respectively). During the other months, there was either no correlation at all (r= -0.05 and r=0.02 during April and July, respectively) or moderate negative correlation (r= -0.26, r= -0.40, and r= -0.42 during May, August, and September, respectively). Instead, O_3 concentration was found to be moderately associated with high pressure *stagnation*, consistent with Chu and Doll's findings (1991) and with Logan's findings (1989) that half of ozone episodes occurred during high pressure stagnation, as defined by Korshover (1976). For this data, the stagnation parameter was statistically significantly correlated with O_3 during May and September (r=0.70 and r=0.62, respectively). The remaining months all demonstrated moderate correlation between stagnation and O_3 (correlation coefficients ranged from r=0.35 to r=0.50). The stagnation "count" parameter displayed moderate positive correlation with O_3 during all months of the study, at statistically significant levels during April (r=0.53), May (r=0.69), and September (r=0.54), indicating that higher O_3 concentrations are more likely during longer periods of time that meet the "stagnation" criteria. The stagnation "event" parameter demonstrated the weakest correlation with O_3 (r=0.02 to r=0.62), most likely due to the small number of stagnation "events" present in the data; April and May were correlated at statistically significanct levels during April and May.

3.2.1.2. SEASONAL ANALYSIS

For the next portion of the analysis, the regional climatological and regional monthly means as described in Section 3.2.1.1 were recomputed for each of the parameters in the study using more than one month for each averaging period. Instead of considering the means for each of the parameters by month, the means were calculated after the months were combined sequentially

according to the number of O_3 exceedence days per month during the study period, thus producing regional *seasonal* means instead of regional *monthly* means for each variable. Again, in order to maintain > 80% data capture efficiency for each of the regional seasonal data subsets, some of the data subsets had to be eliminated from the computations; see Table 3.10 for details.

To begin, the averages for the season consisting of the months of July and August were computed and compared with the results obtained by Vukovich (1994). Strong positive correlation with O_3 was found for temperature (both daily maximum and daily average from 10:00 am to 4:00 p.m. EST; r=0.94 and r=0.87, respectively), dewpoint temperature depression (r=0.91), average Pasquill Index (r=0.76), and stagnation "count" (r=0.54). Strong negative correlation with O_3 was found for relative humidity (r= -0.90) and minimum Pasquill Index (r= -0.88). Table 3.11 demonstrates that the results obtained here are very similar to Vukovich's results. Recall that the Pasquill Stability Index is not only a measure of tropospheric stability, but also a measure of sky cover since the index is based primarily on incoming solar radiation and wind speed. Therefore, comparing the minimum Pasquill Stability parameter with Vukovich's sky cover parameter yields consistent results. The analysis of mean sea level pressure performed here did not yield the same results as Vukovich's analysis, however the analysis of high pressure stagnation and stagnation "count" does yield results similar to Vukovich's. Other research (Chu and Doll, 1991; Meagher, et al., 1987; Mukammal, et al., 1982; Korshover, 1976; King and Vukovich, 1982; Vukovich, 1977) has also found correlation between high ambient O_3 concentrations and high pressure stagnation. The absolute pressure is not necessarily as good of a predictor of O_3 concentrations as is the persistence of high pressure, commonly called "high pressure stagnation". As high pressure persists, O_3 levels continue to rise from one day to the next due to the increased photochemistry that is associated with the clear skies, light winds, and warm temperatures under the high pressure.

Upon completion of the comparison between our results and Vukovich's results for the two month season (July and August only), the season was extended to include the data for the month of June. The regional climatological and regional seasonal means and resulting Pearson correlation coefficients between O_3 and the meteorological parameters were again recomputed. Once again, strong positive correlation with O_3 was clear for temperature (for maximum temperature, $r=0.89$; for average temperature, $r=0.70$), dewpoint depression ($r=0.92$), average Pasquill Index ($r=0.68$), and stagnation "count" ($r=0.50$), while there was a clear negative correlation with relative humidity ($r= -0.90$) and minimum Pasquill Index ($r= -0.84$).

Although June, July, and August make up over 90% of the exceedence days recorded in the dataset, the effect of adding months to the data set during which O_3 exceedences were less common was studied, each time recomputing the regional climatological and regional seasonal means and the resulting Pearson correlation coefficients between O_3 and the meteorological parameters. The months were added sequentially by the number of exceedence days over the study period. After June, July and August, September (24 exceedence days) was added, then May (12 days), then April (1 day), and finally October (no exceedence days). As months were added, the correlation between O_3 and the meteorological parameters became less obvious for each of the parameters that were previously determined to demonstrate very high correlation coefficients, although they still remained statistically significant in most cases. Table 3.12 summarizes the results of this analysis. As before, statistically significant correlation coefficients are given in boldface type. Extending the potential ozone season beyond three months up to seven months yielded roughly the same correlation coefficients as the three month period did. This indicates that a three month ozone season is adequate to capture the meteorological variation present on high ozone days and thus analyze the relationship between ambient O_3 concentrations and meteorological parameters. In addition, the analysis in Section 3.1 demonstrated that over 90% of the exceedence days recorded

for the data set occurred during June, July, and August. Therefore, in the sections that follow, ozone season analysis is based only on the three month ozone season including these three months.

3.2.2. INTERCOMPARISON BETWEEN SITES

Upon determination of a three month timeframe to study the ozone season climatology, each site was analyzed (using only the three month database as defined in Section 3.2.1.), to verify our assumption used during the analysis in Section 3.2.1. which led to the definition of a three-month summer "ozone season". Namely, the assumption used in the original analysis was that each of the sites would independently demonstrate similar correlations between O_3 and the meteorological variables.

Considering each site individually, the regional climatological and regional seasonal means for all variables as well as the resultant Pearson correlation coefficients between O_3 and the meteorological variables were again recomputed. Analyzing each site individually resulted in 134 (nine sites x fifteen years, less one complete year of missing data for RDU183 (1994)) data subsets. As before, there were cases in which data gaps that were not large in relation to the complete data set resulted in very low rates of data capture efficiency in the smaller data subsets. Maintaining data capture efficiency rates above 80% forced deletion of at least one year's worth of data for most of the sites, as indicated in Table 3.13. Consequently, the Pearson correlation coefficients are again computed fewer than fifteen pairs of data points. Although the magnitudes of the correlation coefficients are smaller, they indicate the same results as was obtained when the sites were considered together. Table 3.14 shows the correlation coefficients resulting from individual site analysis; statistically significant values are in boldface type as before.

The homogeneity of the ozone-meteorology correlation coefficients derived from the analysis by site was tested to determine if the coefficients were statistically equivalent. The method

to perform this test was obtained from Steele and Torrie (1980). Briefly, each correlation coefficient is converted to a normal distribution Z:

$$Z = 0.5 \ln \frac{1 + r}{1 - r} \qquad \text{Equation 3.1}$$

since the distribution of the correlation coefficients (r-values) is not expected to maintain symmetry when r approaches -1 or +1. The individual Z-values are then pooled into a weighted average Z* for the region. The summation of the individual squared differences from the pooled Z* is compared to a χ^2 distribution with n-1 degrees of freedom, where n is the number of coefficients being tested for homogeneity.

The homogeneity of the site specific correlation coefficients between O_3 concentration and the meteorological variables was tested for each of the meteorological variables, and each time the χ^2 statistic was below the 5% critical value ($\chi^2 > 15.5$ for 8 degrees of freedom), thus the null hypothesis (i.e., H_0: The coefficients were statistically equivalent across sites) was NOT rejected. The χ^2 values calculated for this analysis are presented in Table 3.15, column a. Using this test of homogeneity, one can conclude that the individual sites do not produce correlation coefficients different from each other. However, there is a chance that even though the sites do not differ when compared to each other, their *pooled* Z* calculated from the individual-site correlation coefficients (as above) may differ from the *regional* correlation coefficient (converted to Z's), since the latter results from averaging the individual-site data *before* performing the correlation analysis. Therefore, the homogeneity of the individual-site pooled Z* calculated above and the regional correlation coefficient actually used in the analysis in Section 3.2.1 (converted to Z) was tested for each meteorological variable. Using the test of homogeneity on only two correlation coefficients results in a more restrictive test, since an outlying correlation coefficient is averaged along with

other coefficients closer to the pooled mean. Consequently, the rejection value at the 5% significance level is much smaller than in the previous case where the number (n) of correlation coefficients was 9 (when n=9, 5% rejection χ^2 =15.5; for n=2, 5% rejection χ^2 =3.84). The results of this analysis are given in Column (b) of Table 3.15. Two parameters differed (i.e., regional correlation coefficients differed from individual-site pooled correlation coefficients) when the test was conducted this way; relative humidity and dewpoint temperature depression (χ^2=5.85 and 6.61, respectively). In both cases, the homogeneity test indicated that the regional correlation coefficient indicates a stronger correlation between relatively dry conditions and higher O_3 concentration (i.e., dewpoint temperature correlation was more positive, while relative humidity correlation was more negative.) Overall, although there may be a slight high bias for the correlation between O_3 concentration and relatively dry conditions using the regional data set, homogeneity across sites for all other variables indicates that the nine sites may be considered as a region when analyzing the correlation between meteorological parameters and O_3 concentrations.

3.2.3. REGIONAL ANALYSIS FOR THE THREE MONTH OZONE SEASON

The months of June, July, and August define the three month ozone season, as discussed at the end of Section 3.2.1.2. Figure 3.3 illustrates O_3 anomalies by year for the three month ozone season. Computed by subtracting the climatological average O_3 concentration from the annual average O_3 concentration for each year, the anomalies indicate whether the annual average O_3 concentration for a given year was higher or lower than the climatological average. The figure indicates that the mean daily maximum O_3 concentration was higher than the climatological average in 1980, 1983, 1986, 1987, 1988, 1990, and 1993 during the three month period of each of those years. On average, the magnitude of the anomalies is about the same, if the average

deviation during years having positive anomalies for a given parameter is compared to that of years having negative anomalies for the same parameter.

By comparison of Figure 3.3 with graphs of the meteorological anomalies for the same three month ozone seasons in Figures 3.4 through 3.7, one can visualize the correlation between O_3 concentration and the meteorological variables. Clearly, the average daily maximum temperature correlates best with O_3 concentration (r=0.89); a positive anomaly on Figure 3.3 corresponds to a positive anomaly on Figure 3.4, and similarly for the negative anomalies in all cases, for each year plotted. Among the indicators of atmospheric moisture (Figure 3.5), relative humidity generally displays negative anomalies while dewpoint temperature depression displays positive anomalies during years which had positive O_3 anomalies, and vice versa. Both relative humidity and dewpoint temperature depression have strong correlations over the three month ozone season (r= -0.90 and r=0.92, respectively). Note that the dewpoint temperature anomalies are much more random in nature and generally smaller than the anomalies for the relative humidity or dewpoint temperature depression; clearly the correlation between it and O_3 concentration is not strong (r= -0.24). In Figure 3.6, note not only that the minimum Pasquill Index generally has negative anomalies and the average Pasquill Index generally has positive anomalies during years which had positive O_3 anomalies (and vice versa), but also note that the magnitude of the minimum Pasquill Index anomalies are generally nearly twice as large as those for the average Pasquill Index. This indicates that the variation on the minimum Pasquill Index is greater, and since its correlation is stronger (r= -0.84 versus r=0.68), it is a better indicator of high O_3 probability. The stagnation parameters' anomalies are illustrated in Figure 3.7. Overall, they demonstrate positive correlation with O_3 concentration, although the correlation is not as strong as some of the other parameters' correlation with O_3 concentration is. However, each of the high pressure stagnation parameters demonstrates more consistent correlation with O_3 than the mean sea level pressure does. For

approximately 2/3 of the years analyzed, positive (negative) annual deviations for the high pressure stagnation parameters correspond to positive (negative) annual deviations for O_3 concentrations. The correlation coefficients for these parameters throughout the three month ozone season were r=0.38 (stagnation parameter), r=0.50 (count parameter), and r=0.49 (event parameter).

3.2.4. OZONE TRENDS AND ANALYSIS

Long term trends for O_3 concentration have been analyzed by many other researchers. Oltmans and Komhyr (1986) noted that two remote northern hemispheric sites had positive trends in O_3 concentration from 1973-1984, while two remote southern hemispheric sites recorded negative trends during the same period. Walker (1985) found O_3 trends to be upward (2.3 %/yr.) in Texas and null (0 %/yr.) in California through 1982. Lindsay et al. (1989) noted that although VOC emissions declined from 1979 to 1985 by as much as 55% in the Atlanta metropolitan area, there was still a slight upward trend in O_3 concentrations (0±1.9 to 1.7±1.6 %/yr.) during the high ozone season (June, July, August) from 1979 to 1987. Simple linear regression of the annually averaged daily maximum O_3 concentration for the three month season was used to determine the trend in ozone concentration for each site in this analysis by decade.

The trends calculated for this analysis were initially calculated in ppmv, since the annually averaged values for O_3 concentration input into the regression function were in ppmv, then converted to percentages to allow direct comparison with Lindsay's calculations. The percentages presented in this discussion were calculated by dividing the slope of the best fit linear regression line (units: ppmv/year) by the overall average O_3 concentration for the timeframe (i.e., 10 years during the 1980s, 5 years during the 1990s) that the regression line was fit against (units: ppmv). Multiplying this fraction of change per year by 100 yields the units presented here (%/year).

The Atlanta sites used in this analysis had trends similar to those calculated by Lindsay during the 1980s; this analysis showed trends of 1.47±1.31%/yr. and 1.23±1.63%/yr. at sites ATL089 and ATL247, respectively. However, during the 1990s, the same sites showed trends of -5.82±4.57 and -4.40±3.91%/yr., respectively at the same sites. Ozone trends for each site are presented in Table 3.16; in general, each site demonstrated an upward trend during the 1980s and a downward trend during the 1990s. One Charlotte site (CLT119J) showed a downward trend during both decades, but a steeper downward trend was discernible during the 1990s. The trend for the Raleigh site (RDU183) is misleading because data for all of 1994 is missing, which would result in an apparent upward trend during the 1990s since a high O_3 year (1993) would be used as the last year in the regression analysis to determine the trend. Consequently, the trends have been deleted for the site. The trends for the remaining sites are plotted in Figure 3.8.

In the previous section, the O_3 trend for each site was individually analyzed and found, in general, to be positive during the 1980s and negative during the 1990s. Regional analysis also demonstrates that the trend of average daily maximum O_3 concentration increased slightly during the 1980s (0.64±1.17%/yr.) and decreased slightly during the 1990s (-2.69±3.37%/yr.). The regional trends are presented graphically in Figure 3.9. Although the magnitude of these trends is not quite as impressive as some of the individual sites' trends, one must keep in mind that they represent *regionally averaged* trends, and it is therefore encouraging to see that the O_3 trend across the Southeast US region has turned around and is now declining.

It has been recognized (Chameides, et al., 1988; Lindsay, et al., 1989; Logan, 1989) that trends in ambient O_3 concentrations do not necessarily indicate that O_3 control strategies in effect are attaining the desired result since interannual variation in meteorology may be the cause of the observed trend. Trend analysis for the meteorological parameters that were shown to be best correlated with the daily maximum O_3 concentration (Sections 3.2.1. and 3.2.3.) was performed in

the same manner as was used to determine the trends for daily maximum O_3 concentration. The analysis revealed that average daily maximum temperature and average daily dewpoint temperature depression both had upward trends (Figures 3.10 and 3.11, respectively) in the 1980s (0.07±0.25%/yr. and 0.38±1.60%/yr.) and downward trends in the 1990s (-0.16±0.89%/yr. and -4.88±6.58%/yr., respectively). In addition, the average daily relative humidity trend (Figure 3.12) was downward in the 1980s (-0.05±0.40%/yr.) and upward in the 1990s (1.23±1.60%/yr.). These findings reinforce the likelihood that the fluctuations of meteorological parameters play an important part in the fluctuations of the ambient O_3 concentration. Optimism may suggest that air quality regulatory policy changes resulting from the Clean Air Act Amendments in 1990 have caused the turn-around in regional O_3 trend. However, further studies will need to be done before a causal relationship can be attached to these correlations, since there certainly is a correlation between trends in meteorological variables and trends in O_3 concentrations.

The trends for the indicators of lower atmospheric stability (Figure 3.13) do not correspond to the trend for O_3 concentration as we would expect them to. Recall from Section 3.2.1. that the minimum daily Pasquill Index was found to be highly inversely correlated with maximum O_3 concentration, while the average Pasquill Index was strongly positively correlated with O_3 concentration, even though we expected both variations of the parameter to be inversely correlated. The peculiarity was attributed to the possibility that instability lasting for the majority of a day could lead to rainshower activity which would in turn remove the precursors to O_3 formation before O_3 could be formed. However, analysis of the trends for these parameters reveal that the minimum Pasquill Stability Index is *positively correlated* with the trend in O_3 concentration (0.21±0.52%/yr. in the 1980s, -0.41±1.69%/yr. in the 1990s), while the average daily Pasquill Stability Index is *negatively correlated* with the trend in O_3 concentration (-0.15±0.17%/yr. in the 1980s, 0.13±0.60%/yr. in the 1990s). An explanation for this apparent

reversal of correlation is not readily apparent; further analysis is necessary to determine how atmospheric stability is correlated with ambient O_3 concentrations and their trends, and to determine which parameter is best suited to represent the correlation.

3.3 ANALYSIS OF STAGNATION

Korshover (1976) related high pressure stagnation with occurrences of high O_3 concentration, particularly in the Southeast United States. He used a pressure gradient technique as a basis of determining areas of stagnation. Korshover's criteria for considering an anticyclone to be stagnant is given in Section 2.4.2.

Using the same criteria, Korshover and Angell (1982, 1983, 1984, 1985, and 1987) reported annual summaries of the high pressure stagnation through 1985. Through personal communication with Angell (November 1995), the raw data indicating which grid points met the Korshover stagnation criteria for days during 1980, 1981, 1982, 1983, and 1984 was obtained. The data set obtained from Angell contained the first day of each stagnation period, along with the number of days meeting stagnation criteria for each grid point at which stagnation occurred. Since we have previously determined (Section 3.2.1) that the ozone season consists only of June, July, and August, this analysis commences with that assumption. When a stagnation event was indicated by the Angell data for any of the grid points corresponding to the location of the nine sites analyzed in this study, the Korshover stagnation event days were tabulated by ozone season (3 months; see Section 3.2.1.) and recorded as either regional (all nine sites) or individual site totals.

The regional seasonal total number of stagnation event days obtained from the Korshover pressure gradient method were divided by the maximum number of seasonal site days across the region (828 site-days, for a 3 month ozone season) in order to obtain *regional seasonal averages* on a daily basis. Finally, the total number of stagnation event days obtained from the Korshover

method for each site (only a three month season was considered during the individual site analysis) was divided by the maximum number of days possible for each site during one 3-month ozone season (92 days) to obtain *site seasonal averages* on a daily basis.

Analysis was performed to determine compatibility between the different high pressure stagnation parameters (that defined by Korshover and those defined in this thesis in Section 2.4.2.) as well as their relative correlation with daily maximum O_3 concentration, based on the years of this study during which data was available for the Korshover stagnation event parameter (1980-1984). Note that each Pearson correlation coefficient presented is based on a maximum of only five (one for each year in the study, less years during which data capture efficiency fell below 80%) pairs (one for each of O_3 concentration and stagnation parameter) of averages. Analysis of the correlation between Korshover's definition of high pressure stagnation and the each of the stagnation parameters as defined in this thesis (stagnation parameter, count, and event) yielded strong correlation (r=0.76, r=0.83, and r=0.77, respectively) between the two methods of defining high pressure stagnation. The strong correlation noted in this portion of the analysis indicates that, regardless of which method is used to define high pressure stagnation, roughly the same days will be highlighted as meeting high pressure stagnation criteria.

Next, since determining the correlation between daily maximum O_3 concentration and meteorological parameters is the focus of this research, further analysis was performed to compare the correlation with daily maximum O_3 for each of the stagnation parameters (stagnation as defined by Korshover as well as stagnation, count, and event as defined in this thesis).

The analysis was begun with intercomparison between the nine sites using a three month ozone season to ensure that the regional grouping assumption remains true for this pared down data set. As described in Section 3.2.3, when the original data set was pared down to data subsets containing data for only one season's worth of days at each site, some data gaps that were small

relative to the complete data set were amplified on the data subsets, resulting in low rates of data capture efficiency in some of the 45 (nine sites x five years) data subsets. Again, those data subsets that contained fewer than 73.6 data days (80% of the total possible 92 data days during the June, July, August ozone season) were removed before the correlation coefficients were calculated, resulting in the loss of 5 data subsets, as shown in Table 3.13. Note that for one Charlotte site (CLT119J), the primary high O_3 year was removed from the analysis as a result of meeting the data capture efficiency standard. Consequently, the correlations between O_3 and some of the stagnation parameters were misleading for the site. Upon further analysis, it was found that some of the missing data for that site corresponded with one of the periods that Korshover found to meet his stagnation event criteria. For this reason, site CLT119J was removed from the individual site analysis; the correlation coefficients in the following section refer to only the remaining eight sites.

The results of the analysis of correlation between daily maximum O_3 concentration and stagnation parameters by site are presented in Table 3.17. The stagnation parameter (as defined using the numerical method) demonstrated positive correlation with daily maximum O_3 concentration (r=0.07 to r=0.70) for all sites. The count parameter also showed similar correlations for each site, demonstrating slightly stronger correlation with O_3 concentration (r=0.14 to r=0.76) than the basic stagnation parameter did for most sites. Neither site in Atlanta had any occurrences meeting stagnation event criteria, therefore correlations for that parameter for those sites could not be calculated. However, the remaining sites all showed positive correlation between meeting event criteria and O_3 concentration; with correlation coefficients ranging from r=0.09 to r=0.78. Korshover's stagnation event parameter generated very strong positive correlations for all sites except the Nashville site (BNA165, r=0.10); the range of correlation coefficients for the other sites was r=0.50 to r=0.99. As was performed in Section 3.2.3, the homogeneity of the correlation coefficients was tested across sites for each parameter. The χ^2 test of homogeneity failed to find

statistically significant differences between sites for each of the parameters. The χ^2 values for the stagnation parameter, stagnation event, and stagnation count were 3.79, 1.26, and 3.15, respectively. Korshover's stagnation parameter showed larger differences in correlation between sites with $\chi^2 = 12.14$, although the differences were still not statistically significant (the rejection region in each of these cases was $\chi^2 > 15.5$, since each test had 8 degrees of freedom). Upon verification that each parameter gave statistically equivalent correlation coefficients across sites, another test was performed to determine if the correlation coefficients between O_3 and each of the stagnation parameters determined for the regional seasonal analysis were statistically equivalent. All four of the stagnation parameters were compared and found to be statistically equivalent (χ^2=1.36; reject H_0 at the 5% significance level if χ^2>7.81 with 3 degrees of freedom.) In addition, each of the stagnation parameters defined in this work were compared to Korshover's stagnation event parameter on a one-to-one basis, with the result that each of them is independently statistically equivalent to Korshover's parameter (z=-1.097, -0.836, and -0.432, respectively; reject at the 5% significance level if |z|>1.96.)

The number of days meeting stagnation criteria were plotted for the entire Southeastern US (over 130 sites) and isoplethed to further analyze occurrences of high pressure stagnation for the region. Appendix 1 contains maps with the isopleths for the climatologically averaged (1980-1994) number of stagnation days per annual ozone season (June-August of each year), as well as isoplethed maps for the number of high pressure stagnation days per ozone season for each year during the study period. Darker (lighter) shades on the maps indicate more (fewer) days meeting the high pressure stagnation criteria. By simple subjective analysis of the shading on the maps, one can see that 1983, 1986, 1987, 1988, 1990, and 1993 are generally darker than the climatological averaged map. Other years (particularly 1985, 1989, 1991, 1992, and 1994), in general, have lighter shading, indicating that these years have fewer than the climatological average of days

meeting the high pressure stagnation criteria. Notice by comparison with Figure 3.3 that the years with darker (lighter) shading on these figures were previously noted as year that had anomalously high (low) O_3 concentrations throughout the ozone season. Closer examination of the actual isopleths on the maps will verify that the subjective analysis made above using only the shading (i.e., darker or lighter than the climatological mean shading) is generally true for most locations throughout the Southeast US. The *location* of high concentrations of high pressure stagnation may also play an important part in determining which years have abnormally high (or low) O_3 concentrations on average. For example, examine the high pressure stagnation maps for 1986, 1987 and 1988. All three years appear darker than the climatological average overall and all three years had higher than average O_3 concentrations. However, 1988's ozone anomaly was much higher than that for either 1986 or 1987. This may be due in part to the fact that the greatest concentration of high pressure stagnation during 1988 was further north in the more industrial states along the Ohio River Valley, while the greatest concentration of high pressure stagnation during 1986 and 1987 was in the less industrial Gulf Coast States. Other authors (Altshuller, 1978; King and Vukovich, 1982; Lindsay and Chameides, 1988; Vukovich, 1977; Wolff and Lioy, 1980) have noted that high pressure stagnation in conjunction with larger emissions of NO_X and VOC's result in high ambient O_3 concentrations. Ozone precursors emitted in more industrial areas may lead to elevated O_3 concentrations in the Southeast US region via transport of the precursors as high pressure systems migrate south and east. Further analysis into the location of concentrated areas of high pressure stagnation and the direction of the high pressure center's migration may lead to a better understanding of the effect that high pressure stagnation has on increasing ambient O_3 concentrations.

3.4. DISCUSSION AND CONCLUSIONS

An extensive statistical analysis of O_3 concentrations and relevant meteorological parameters was performed to determine the effect of meteorological changes on ambient O_3 concentrations in the urban and semi-urban environment on a regional basis throughout the Southeast United States.

Statistics were compiled for those days during which the maximum O_3 concentration exceeded the NAAQS for O_3 (0.120 ppmv). It was found with statistical significance at the 5% level that days in exceedence of the NAAQS have, on average:

- higher daily maximum temperature
- lower average wind speed
- lower average relative humidity
- larger average dewpoint temperature depression
- higher average daily Pasquill Stability Index
- lower minimum daily Pasquill Stability Index

and are better associated with high pressure stagnation. Although exceedences of the NAAQS for O_3 do not result solely from any one of these relationships, some combination of these meteorological factors, along with the proper proportions of emissions of O_3 precursors (NO_X and VOC's), may lead to ambient O_3 concentrations in excess of the NAAQS standard.

The correlation between average daily maximum O_3 concentration and various meteorological variables was analyzed on a monthly basis from April through October during the years from 1980 to 1994. The correlations (both positive and negative) were found to be the strongest during the summer months, particularly June, July, and August. These findings are consistent with others (Chamiedes and Cowling, 1995; Logan, 1989; McNider, et al., 1993; Meagher, et al., 1987; Vukovich, 1994; Warmbt, 1979), who noted that O_3 concentrations are

highest during periods characterized with warm, dry, and sunny conditions. Upon determination of a three month "ozone season" from June to August of each year, a *seasonal* analysis of correlation was also performed for the region. It was also noted that, climatologically, over 90% of the O_3 exceedence site-days for the region occurred during the "ozone season" from June to August of each year. As the potential ozone season was extended beyond the three month timeframe the strength of the correlations between O_3 concentration and the meteorological variables diminished slightly, but remained statistically significant. Based on the results obtained from this analysis, future O_3 studies for urban and semi-urban areas in the Southeast United States should be based on a three month "ozone season" from June to August of each year. In addition, changes in O_3 concentration are well correlated with changes in meteorological indicators of temperature, lower tropospheric moisture, and lower tropospheric stability. Among the various parameters studied to represent these atmospheric variables, daily maximum temperature, average daily relative humidity, average daily dewpoint temperature depression, and minimum Pasquill Stability Index, were found to demonstrate the strongest correlation.

Although high pressure stagnation was positively correlated with daily maximum O_3 concentration, the correlation between O_3 concentration and high pressure stagnation was not found to be statistically significant for those sites analyzed during the period of time covered by this study. The high pressure stagnation parameters used in this analysis (defined in Section 2.4.2.) were examined further and compared with that defined by Korshover (1976). The correlation between O_3 concentration and each of the parameters was found to agree well for the limited dataset (five years) that was available for intercomparison. Absolute pressure is not necessarily as good of a predictor of O_3 concentrations as is the persistence of high pressure, commonly called "high pressure stagnation". As high pressure persists, O_3 levels continue to rise from one day to the next because of the increased photochemistry that is associated with the clear skies, light winds,

and warm temperatures under the high pressure. Regional analysis suggests that not only the presence of high pressure stagnation, but also the *location* of concentrated areas of high pressure stagnation may play an important role in whether or not ambient O_3 levels are increased. Further study is needed to determine what effect high pressure stagnation has toward elevating O_3 concentrations above the NAAQS.

Long term trends of O_3 were also studied. Although statistical significance was not found, O_3 concentrations were found to have increased slightly (+0.45±0.83 ppb/yr., +0.64±1.17 %/yr.) during the 1980s and decreased slightly (-1.87±2.34 ppb/yr., -2.69±3.37 %/yr.) during the 1990s. The observed trends in O_3 concentration may be caused by reduction of chemical precursor emissions, as brought about by the 1990 Amendments to the Clean Air Act; however, the role of meteorology cannot be ignored. The trends in O_3 concentration correspond very well with trends in meteorological variables calculated for the same sites over the same period. The trend for meteorological variables that demonstrated positive correlation with O_3 concentration (i.e., daily maximum temperature and dewpoint temperature depression) was the same as that for O_3 concentration during both decades, while the trend for a meteorological variable that demonstrated negative correlation with O_3 concentration (i.e., relative humidity) was opposite that for O_3 concentration during both decades. Correlation of trends in O_3 concentration and meteorological variables in this manner reinforces earlier findings that higher ambient O_3 concentrations occur more often during summers that are warmer and drier (Warmbt, 1979; Meagher, et al., 1987; Chameides and Cowling, 1995; Vukovich, 1994). However, this study cannot place a causal relationship between the O_3 and meteorological parameters' trends calculated. Meteorology may be causing the trends noted in ambient O_3 concentrations since O_3 is photochemically produced and depends greatly on the effects of meteorology. However, since O_3 is a greenhouse gas, the

meteorological trends calculated in this paper for the 1990s could be the result of properly reducing O_3's chemical precursors, which in turn reduce ambient O_3 concentrations.

The interaction between the physics (meteorology) and chemistry that leads to high concentrations of O_3 in the lower troposphere is what makes compliance with the NAAQS for O_3 a challenge. Although exceedences of the NAAQS for O_3 do not result from any one of these relationships, some combination of the meteorological factors, along with the proper proportions of emissions of O_3's chemical precursors (NO_X and VOC's), may lead to ambient O_3 concentrations in excess of the NAAQS. Further research is needed to determine how the interaction between the chemistry of O_3 precursors and physics of the atmosphere lead to ambient O_3 concentrations that may be hazardous to the health and welfare of plants and animals exposed to high concentrations of O_3.

Table 3.1. Statistics for exceedence site-days during May, 1980-1994. Unless otherwise indicated, the parameters are averages based on hourly observations from 10:00 a.m. to 4:00 p.m. EST. The numbers in parentheses indicate the number of daily averages (unless otherwise indicated) used to compute the overall monthly average for each parameter.

parameter	**statistic**	**Month = May**	
		exceedence days (12)	all data (3618)
maximum temp (°F)	average	**85.3**	79.4
	std. dev.	**3.2**	6.3
wind speed (knots)	average	**4.3**	5.9
	std. dev.	**2.1**	2.3
relative humidity (%)	average	70.4	73.2
	std. dev.	9.8	12.5
dewpoint temp (°F)	average	56.9	55.4
	std. dev.	5.3	8.5
dewpoint depression (°F)	average	10.1	9.1
	std. dev.	3.7	4.9
pressure (mb)	average	**1018.2**	1016.5
	std. dev.	**2.3**	4.3
average Pasquill Index	average	4.83	4.65
	std. dev.	0.58	0.50
minimum Pasquill Index	average	**2.33**	3.08
	std. dev.	**0.65**	0.77
stagnation parameter	average	**0.50**	0.10
	std. dev.	**0.52**	0.29
stagnation events	average	0.00	0.00
	std. dev.	0.00	0.06
stagnation count	average	**1.25**	0.13
	std. dev.	**1.42**	0.47

Table 3.2. Statistics for exceedence site-days during June, 1980-1994. Unless otherwise indicated, the parameters are averages based on hourly observations from 10:00 a.m. to 4:00 p.m. EST. The numbers in parentheses indicate the number of daily averages (unless otherwise indicated) used to compute the overall monthly average for each parameter.

parameter	**statistic**	**Month = June**	
		exceedence days (108)	all data (3736)
maximum temp (°F)	average	**91.8**	86.4
	std. dev.	**3.8**	5.2
wind speed (knots)	average	**5.2**	5.7
	std. dev.	**1.5**	2.0
relative humidity (%)	average	**65.0**	75.3
	std. dev.	**10.4**	10.9
dewpoint temp (°F)	average	**62.8**	63.9
	std. dev.	**5.8**	5.9
dewpoint depression (°F)	average	**12.9**	8.5
	std. dev.	**4.5**	4.3
pressure (mb)	average	**1016.7**	1016.0
	std. dev.	**3.8**	3.8
average Pasquill Index	average	**4.77**	4.61
	std. dev.	**0.36**	0.46
minimum Pasquill Index	average	**2.30**	2.98
	std. dev.	**0.52**	0.78
stagnation parameter	average	**0.24**	0.12
	std. dev.	**0.43**	0.32
stagnation events	average	0.00	0.00
	std. dev.	0.00	0.06
stagnation count	average	**0.35**	0.16
	std. dev.	**0.70**	0.51

Table 3.3. Statistics for exceedence site-days during July, 1980-1994. Unless otherwise indicated, the parameters are averages based on hourly observations from 10:00 a.m. to 4:00 p.m. EST. The numbers in parentheses indicate the number of daily averages (unless otherwise indicated) used to compute the overall monthly average for each parameter.

parameter	statistic	Month = July	
		exceedence days (142)	all data (3913)
maximum temp (°F)	average	**95.0**	89.4
	std. dev.	**3.3**	5.3
wind speed (knots)	average	**5.1**	5.4
	std. dev.	**1.5**	1.8
relative humidity (%)	average	**69.3**	78.0
	std. dev.	**9.5**	10.0
dewpoint temp (°F)	average	**67.2**	68.3
	std. dev.	**4.1**	3.9
dewpoint depression (°F)	average	**11.1**	7.6
	std. dev.	**4.2**	4.0
pressure (mb)	average	1017.5	1017.1
	std. dev.	2.8	3.0
average Pasquill Index	average	**4.82**	4.64
	std. dev.	**0.44**	0.46
minimum Pasquill Index	average	**2.36**	2.92
	std. dev.	**0.51**	0.79
stagnation parameter	average	**0.39**	0.15
	std. dev.	**0.49**	0.35
stagnation events	average	0.03	0.02
	std. dev.	0.21	0.15
stagnation count	average	**0.68**	0.25
	std. dev.	**1.14**	0.79

Table 3.4. Statistics for exceedence site-days during August, 1980-1994. Unless otherwise indicated, the parameters are averages based on hourly observations from 10:00 a.m. to 4:00 p.m. EST. The numbers in parentheses indicate the number of daily averages (unless otherwise indicated) used to compute the overall monthly average for each parameter.

parameter	**statistic**	**Month = August**	
		exceedence days (102)	all data (3954)
maximum temp (°F)	average	**94.3**	87.5
	std. dev.	**4.3**	5.4
wind speed (knots)	average	**4.8**	5.1
	std. dev.	**1.4**	1.9
relative humidity (%)	average	**72.1**	79.7
	std. dev.	**9.3**	8.8
dewpoint temp (°F)	average	**68.4**	67.3
	std. dev.	**3.9**	4.3
dewpoint depression (°F)	average	**10.0**	6.8
	std. dev.	**3.9**	3.3
pressure (mb)	average	**1016.3**	1017.5
	std. dev.	**3.0**	3.2
average Pasquill Index	average	**4.98**	4.79
	std. dev.	**0.48**	0.55
minimum Pasquill Index	average	**2.35**	2.98
	std. dev.	**0.61**	0.79
stagnation parameter	average	**0.33**	0.19
	std. dev.	**0.47**	0.40
stagnation events	average	0.02	0.01
	std. dev.	0.14	0.09
stagnation count	average	**0.56**	0.30
	std. dev.	**0.94**	0.72

Table 3.5. Statistics for exceedence site-days during September, 1980-1994. Unless otherwise indicated, the parameters are averages based on hourly observations from 10:00 a.m. to 4:00 p.m. EST. The numbers in parentheses indicate the number of daily averages (unless otherwise indicated) used to compute the overall monthly average for each parameter.

parameter	statistic	Month = September	
		exceedence days (24)	all data (3694)
maximum temp (°F)	average	**90.7**	81.9
	std. dev.	**4.6**	6.9
wind speed (knots)	average	**4.3**	5.2
	std. dev.	**1.7**	2.2
relative humidity (%)	average	**71.0**	79.1
	std. dev.	**8.4**	9.9
dewpoint temp (°F)	average	63.3	61.2
	std. dev.	6.4	8.2
dewpoint depression (°F)	average	**10.1**	6.9
	std. dev.	**3.5**	3.6
pressure (mb)	average	1018.3	1018.9
	std. dev.	2.9	4.2
average Pasquill Index	average	**5.38**	4.92
	std. dev.	**0.35**	0.62
minimum Pasquill Index	average	**2.46**	3.12
	std. dev.	**0.51**	0.75
stagnation parameter	average	**0.63**	0.22
	std. dev.	**0.49**	0.42
stagnation events	average	0.04	0.01
	std. dev.	0.20	0.13
stagnation count	average	**1.17**	0.38
	std. dev.	**1.20**	0.86

Table 3.6. Statistics for exceedence site-days during Ozone Season (June-August), 1980-1994. Unless otherwise indicated, the parameters are averages based on hourly observations from 10:00 a.m. to 4:00 p.m. EST. The numbers in parentheses indicate the number of daily averages (unless otherwise indicated) used to compute the overall monthly average for each parameter.

parameter	statistic	Ozone Season (June - August)	
		exceedence days (352)	all data (11603)
maximum temp (°F)	average	**93.8**	87.8
	std. dev.	**4.0**	5.5
wind speed (knots)	average	**5.0**	5.4
	std. dev.	**1.5**	1.9
relative humidity (%)	average	**68.8**	77.7
	std. dev.	**10.1**	10.1
dewpoint temp (°F)	average	66.2	66.6
	std. dev.	5.2	5.1
dewpoint depression (°F)	average	**11.3**	7.6
	std. dev.	**4.4**	3.9
pressure (mb)	average	1016.9	1016.9
	std. dev.	3.2	3.4
average Pasquill Index	average	**4.85**	4.68
	std. dev.	**0.43**	0.50
minimum Pasquill Index	average	**2.34**	2.96
	std. dev.	**0.54**	0.79
stagnation parameter	average	**0.33**	0.15
	std. dev.	**0.47**	0.36
stagnation events	average	0.02	0.01
	std. dev.	0.15	0.11
stagnation count	average	**0.55**	0.24
	std. dev.	**0.97**	0.69

Table 3.7. Summary of regional monthly data subsets data capture efficiency requirements and years not meeting those requirements.

Month	data capture efficiency		subsets deleted (<80% data capture)	
	maximum n	80%	year	actual n
April	270	216	1980	120
May	279	223.2	1980 1981	144 212
June	270	216	1980	184
July	279	223.2	1980	209
August	279	223.2	none	
September	270	216	none	
October	279	223.2	1981 1982 1982 1994	215 193 190 213

Table 3.8. Regional Climatological (1980-1994) monthly means for daily maximum O_3 concentration.

Month	Regional Daily Max. Ozone Concentration, PPM
April	0.0565±0.0048
May	0.0640±0.0056
June	0.0708±0.0091
July	0.0717±0.0096
August	0.0691±0.0090
September	0.0586±0.0052
October	0.0465±0.0037

Table 3.9. Correlation coefficients between daily average maximum O_3 concentration and meteorological variables by month. Unless otherwise indicated, the parameters are averages based on hourly observations from 10:00 a.m. to 4:00 p.m. EST. The number in parentheses after each month's name indicates the number of pairs of averages that went into the calculation of each correlation coefficient.

parameter	**Month (n)**						
	April (14)	May (13)	June (14)	July (14)	Aug. (15)	Sept. (15)	Oct. (11)
max. temp (°F)	**0.53**	0.17	**0.68**	**0.83**	**0.94**	0.42	0.19
average temp (°F)	0.32	-0.11	0.24	**0.66**	**0.91**	0.04	-0.04
wind speed (knots)	-0.19	-0.32	0.12	-0.23	-0.10	**-0.63**	0.07
relative humidity (%)	**-0.53**	-0.39	**-0.85**	**-0.85**	**-0.90**	**-0.52**	-0.45
dewpoint temp (°F)	0.02	-0.23	-0.50	-0.08	**0.61**	-0.24	-0.19
dewpoint depression (°F)	**0.56**	0.43	**0.87**	**0.85**	**0.92**	**0.53**	0.47
pressure (mb)	-0.05	-0.26	0.45	0.02	-0.40	-0.42	0.70
average Pasquill Index	**0.63**	**0.79**	0.44	**0.79**	0.50	0.49	0.34
minimum Pasquill Index	**-0.77**	**-0.62**	**-0.77**	**-0.88**	**-0.77**	**-0.64**	**-0.59**
stagnation parameter	0.37	**0.70**	0.35	0.50	0.35	**0.62**	0.42
stagnation events	**0.52**	**0.62**	0.02	0.21	0.19	0.40	0.18
stagnation count	**0.53**	**0.69**	0.34	0.38	0.32	**0.54**	0.38

Table 3.10. Summary of regional seasonal data subsets capture efficiency requirements and years not meeting those requirements.

Season		data capture efficiency		data subset deleted (<80%)	
months	period	maximum n	80%	year	actual n
2	July-August	558	446.4	none	
3	June-August	828	662.4	none	
4	June-September	1098	878.4	none	
5	May-September	1377	1101.6	1980	1050
6	April-September	1647	1317.6	1980	1170
7	April-October	1926	1540.8	1980	1398

Table 3.11. Comparison between correlation coefficients found by Vukovich and those found in this work. Results are based on a two-month ozone season (July and August only).

Parameter	Researcher	
	Vukovich	This Work
Temperature	0.91	0.94
Pressure		
mean sea level pressure	0.33	-0.30
high pressure stagnation	--	0.49
stagnation "count"	--	0.54
Wind Speed	-0.42	-0.14
Solar Radiation		
sky cover	-0.87	--
min. Pasquill Index	--	-0.88
Atmospheric Moisture		
dewpoint temperature	0.31	0.25
dewpoint temp. depression	--	0.91
relative humidity	--	-0.90
precipitation	-0.91	--

Table 3.12. Correlation coefficients between daily average maximum O_3 concentration and meteorological variables by length of ozone season (see text). Unless otherwise indicated, the parameters are averages based on hourly observations from 10:00 a.m. to 4:00 p.m. EST. The number in parentheses after each season length (in months; see text) indicates the number of pairs of averages that went into the calculation of each correlation coefficient.

parameter	**Length of ozone season, months (n)**					
	2 (15)	3 (15)	4 (15)	5 (14)	6 (14)	7 (14)
max. temp (°F)	**0.94**	**0.89**	**0.86**	**0.82**	**0.75**	**0.62**
average temp (°F)	**0.87**	**0.70**	**0.67**	**0.57**	0.47	0.25
wind speed (knots)	-0.14	-0.07	-0.13	-0.12	0.07	0.06
relative humidity (%)	**-0.90**	**-0.90**	**-0.81**	**-0.72**	**-0.69**	**-0.78**
dewpoint temp (°F)	0.25	-0.24	-0.01	0.02	-0.05	-0.33
dewpoint depression (°F)	**0.91**	**0.92**	**0.84**	**0.76**	**0.74**	**0.81**
pressure (mb)	-0.30	0.44	0.08	-0.07	**-0.61**	**-0.56**
average Pasquill Index	**0.76**	**0.68**	**0.60**	**0.53**	0.50	**0.71**
minimum Pasquill Index	**-0.88**	**-0.84**	**-0.80**	**-0.75**	**-0.74**	**-0.77**
stagnation parameter	0.49	0.38	0.35	0.35	0.24	0.29
stagnation events	0.41	0.49	0.41	0.40	0.39	0.39
stagnation count	**0.54**	0.50	0.40	0.39	0.31	0.34

Table 3.13. Seasonal data subsets by site. Note: In the data subsets deleted columns, those data subsets marked with an asterisk were also deleted from the Analysis of Stagnation Days comparison with Korshover in Section 3.3.

Site	data capture efficiency		data subsets deleted (<80%)	
	maximum n	80%	year	actual n
ATL089	92	73.6	1992	70
ATL247	92	73.6	1980 *	40
BNA037	92	73.6	1981 *	67
BNA165	92	73.6	1980 *	61
CLT119H	92	73.6	1980 *	42
CLT119I	92	73.6	none	
CLT119J	92	73.6	1983 *	73
GSO081	92	73.6	1986	70
RDU183	92	73.6	(1994)	no data

Table 3.14. Correlation coefficients between daily average maximum O_3 concentration and meteorological variables by site for a three month ozone season (June, July, August). Unless otherwise indicated, the parameters are averages based on hourly observations from 10:00 a.m. to 4:00 p.m. EST. The number in parentheses after each site code indicates the number of pairs of averages that went into the calculation of each correlation coefficient. Neither site ATL089 nor site ATL247 had any days meeting stagnation event criteria for the period studied.

parameter	**Site**								
	ATL089 (14)	ATL247 (14)	BNA037 (14)	BNA165 (14)	CLT119H (14)	CLT119I (15)	CLT119J (14)	GSO081 (14)	RDU183 (14)
max. temp (°F)	**0.62**	**0.65**	**0.71**	**0.71**	**0.76**	**0.79**	**0.74**	**0.69**	**0.78**
average temp (°F)	0.39	0.50	**0.61**	**0.72**	**0.59**	**0.59**	**0.58**	0.42	0.42
wind speed (knots)	-0.25	-0.29	-0.32	-0.19	-0.24	-0.07	0.20	-0.18	0.28
relative humidity (%)	**-0.61**	**-0.61**	**-0.69**	**-0.69**	**-0.72**	**-0.77**	**-0.74**	-0.41	-0.43
dewpoint temp (°F)	-0.29	-0.30	-0.17	-0.07	-0.28	-0.30	-0.26	-0.09	-0.02
dewpoint depression (°F)	**0.63**	**0.62**	**0.70**	**0.70**	**0.73**	**0.78**	**0.75**	0.42	0.45
pressure (mb)	0.23	0.42	0.43	0.26	0.23	0.07	-0.13	0.24	-0.01
average Pasquill Index	0.47	**0.56**	**0.66**	0.46	**0.55**	**0.62**	**0.58**	**0.54**	0.35
minimum Pasquill Index	**-0.79**	**-0.88**	-0.48	**-0.69**	**-0.75**	**-0.79**	**-0.80**	**-0.58**	**-0.64**
stagnation parameter	0.19	0.19	**0.67**	0.28	0.28	0.24	0.11	0.43	0.24
stagnation events	.	.	0.48	0.10	0.42	0.34	0.26	0.36	0.52
stagnation count	0.20	0.18	**0.70**	0.28	0.40	0.34	0.21	0.44	0.44

Table 3.15. χ^2 values resulting from tests of homogeneity across correlation coefficients for individual sites. χ^2 values marked with an asterisk (*) indicate those that are significant at the 5% level.

	(a.) site intercomparison	(b.) pooled sites versus region
rejection χ^2 value	15.5	3.84
degrees of freedom	8	1
PARAMETER		
max. temp (°F)	1.26	2.95
average temp (°F)	2.22	0.72
wind speed (kts)	4.25	0.03
relative humidity (%)	3.82	5.85*
dewpoint temp (°F)	1.19	0.02
dewpoint depression (°F)	3.96	6.61*
pressure (mb)	3.44	0.77
average Pasquill Index	1.48	0.58
minimum Pasquill Index	5.97	1.00
stagnation parameter	3.82	0.07
stagnation events	2.26	0.67
stagnation count	3.90	0.29

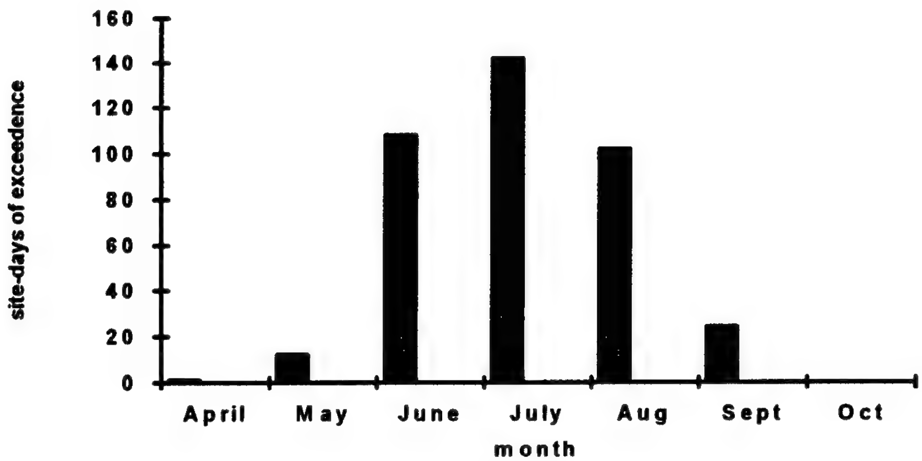
Table 3.16. Trends for daily maximum O_3 concentration for nine urban and semi-urban sites in the Southeast United States. The trends for Atlanta sites marked with an asterisk (*) are those determined by Lindsay et al. (1989) at the same sites for the period 1979-1987.

Site	**Trend in Daily Maximum Ozone Concentration**					
	1980-1989			**1990-1994**		
	avg. daily maximum concentration (ppbv)	**trend (ppbv/yr.)**	**trend (%/yr.)**	**avg. daily maximum concentration (ppbv)**	**trend (ppbv/yr.)**	**trend (%/yr.)**
ATL089	73.9	0.91±1.20	1.23±1.63 1.7±1.6*	71.3	-4.15±3.26	-5.82±4.57
ATL247	74.3	1.09±0.97	1.47±1.31 0.3±1.5*	75.3	-3.32±2.95	-4.40±3.91
BNA037	57.5	-0.02±1.25	-0.04±2.18	52.3	-1.43±2.55	-2.73±4.88
BNA165	71.5	2.40±0.68	3.36±0.95	76.2	-0.46±2.25	-0.60±2.96
CLT119H	73.9	0.47±0.79	0.63±1.07	70.4	-1.92±2.17	-2.73±3.08
CLT119I	71.6	0.39±1.16	0.55±1.62	67.5	-3.00±2.43	-4.45±3.60
CLT119J	77.4	-0.27±0.95	-0.35±1.23	74.5	-2.42±2.37	-3.25±3.19
GSO081	70.9	0.40±0.86	0.56±1.21	69.4	-0.40±2.93	-0.57±4.22
RDU183	71.0	see text	see text	66.0	see text	see text
ENTIRE REGION AVG.	71.3	0.45±0.83	0.64±1.17	69.3	-1.87±2.34	-2.69±3.37

Table 3.17. Correlation coefficients comparing two methods of defining high pressure stagnation, based on a three month ozone season.

		Parameter			
site	n	stagnation parameter	stagnation event	stagnation count	Korshover stagnation
ATL089	5	0.42	.	**0.56**	**0.79**
ATL247	4	0.11	.	0.30	**0.79**
BNA037	4	**0.70**	0.19	**0.76**	**0.99**
BNA165	4	**0.64**	0.09	0.47	0.10
CLT119H	4	**0.53**	**0.55**	**0.52**	**0.80**
CLT119I	5	0.07	**0.54**	0.14	**0.96**
GSO081	5	**0.63**	0.17	**0.54**	**0.62**
RDU183	5	**0.53**	**0.78**	**0.68**	0.50

Figure 3.1. Number of site-days of exceedence by month, 1980-1994.



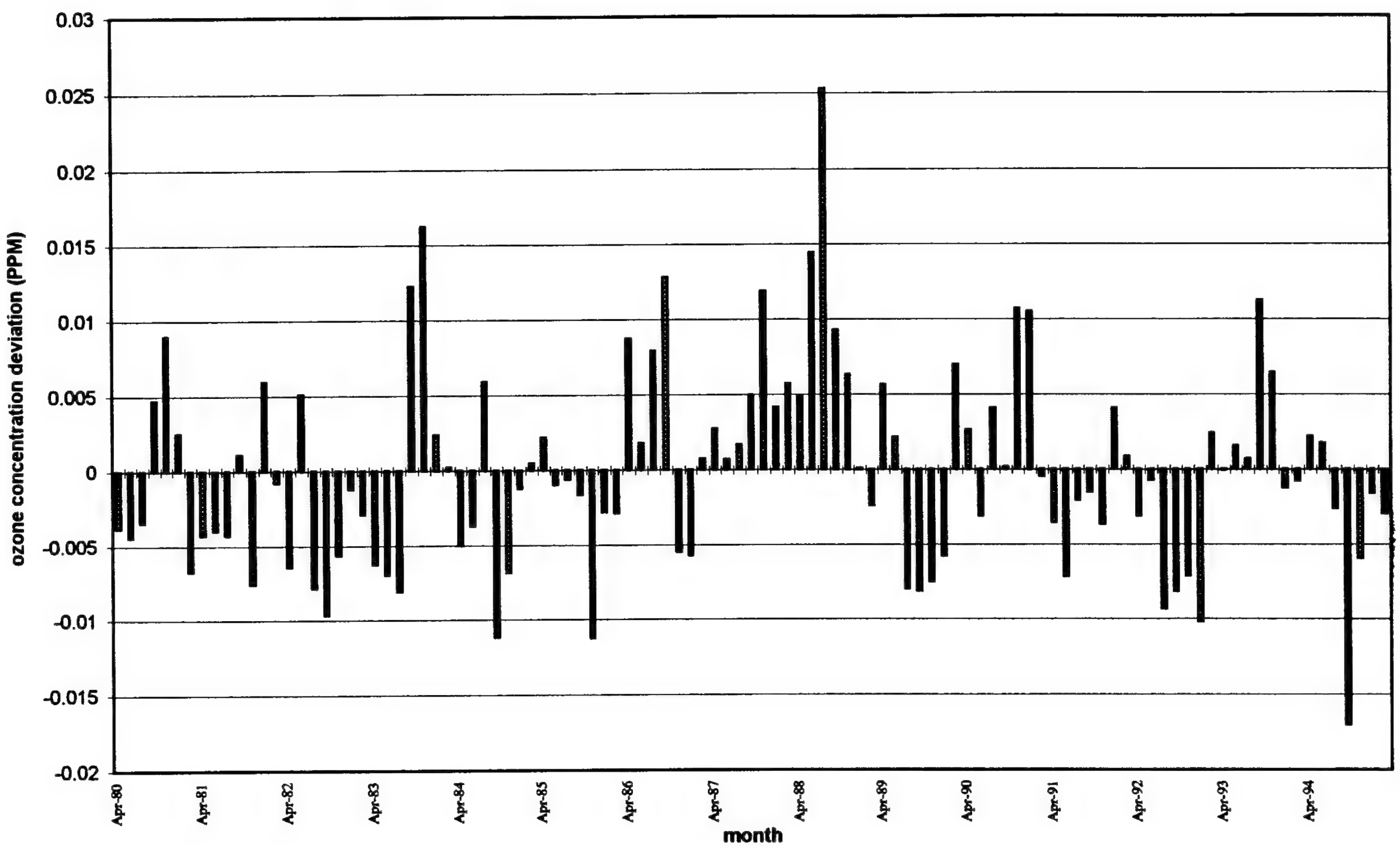


Figure 3.2. Deviation of average daily maximum ozone concentration (ppm) by month. Deviations are computed by comparing each month with the average for that month over the entire 15-year period of study.

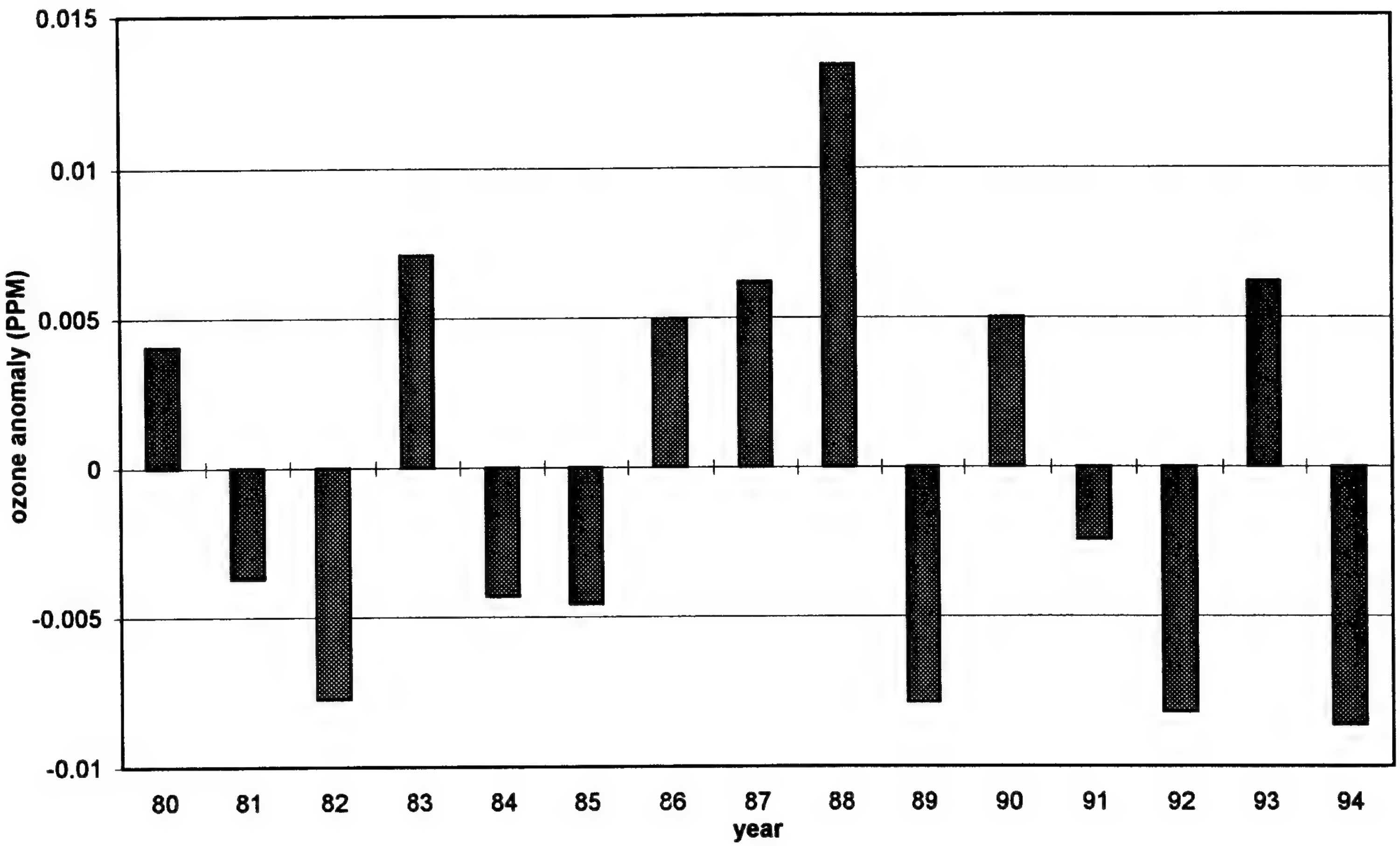


Figure 3.3. The anomaly of the surface daily maximum ozone concentration (ppm) for each ozone season (June-August) in the 15-year period averaged over all sites.

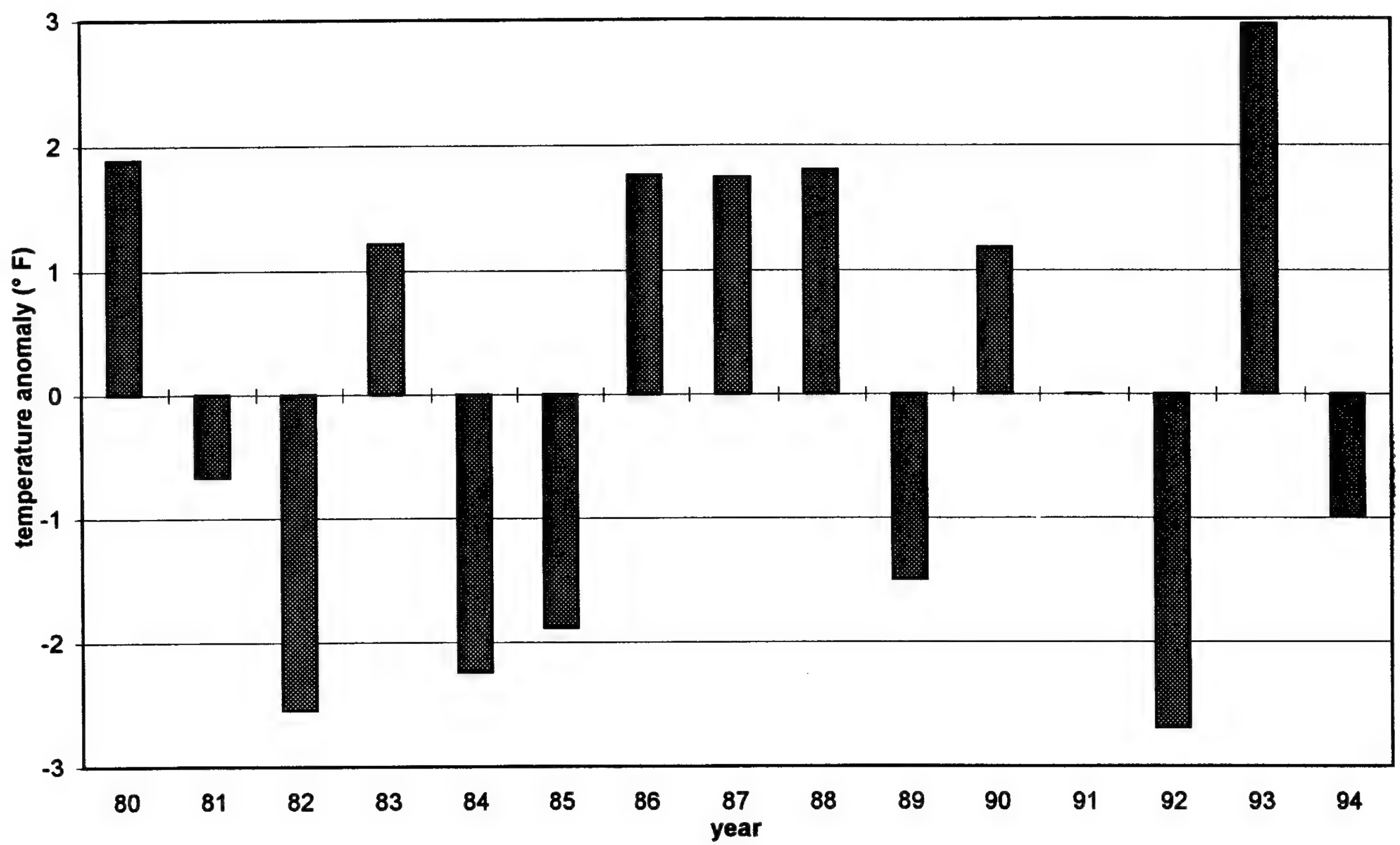


Figure 3.4. The anomaly for the daily maximum temperature (° F) for each ozone season (June-August) in the 15-year study period averaged over all sites.

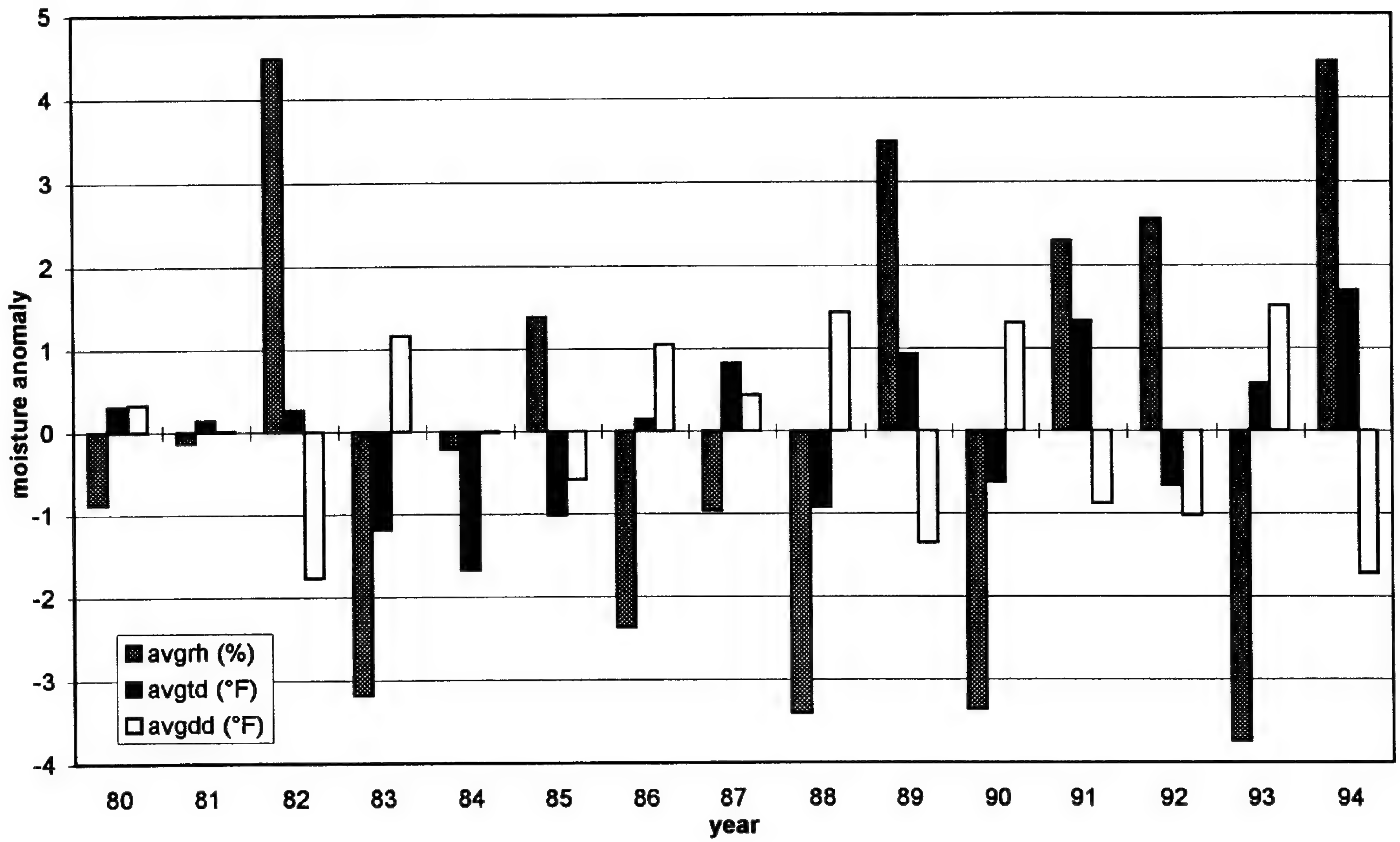


Figure 3.5. Anomalies for indicators of atmospheric moisture for each ozone season (June-August) in the 15-year study period averaged over all sites.

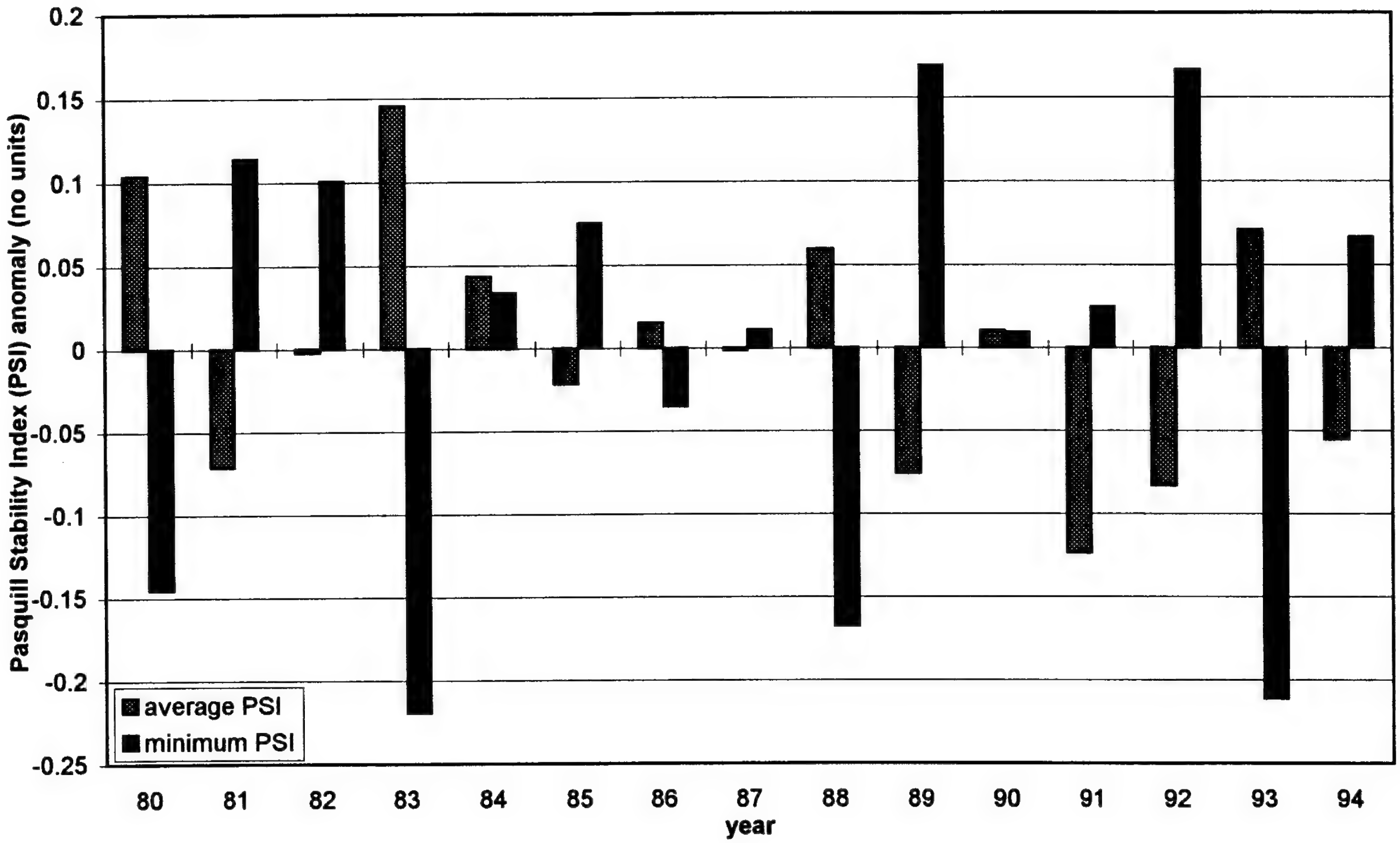


Figure 3.6. Anomalies for Pasquill Stability Index for each ozone season (June-August) in the 15-year study period averaged over all sites.

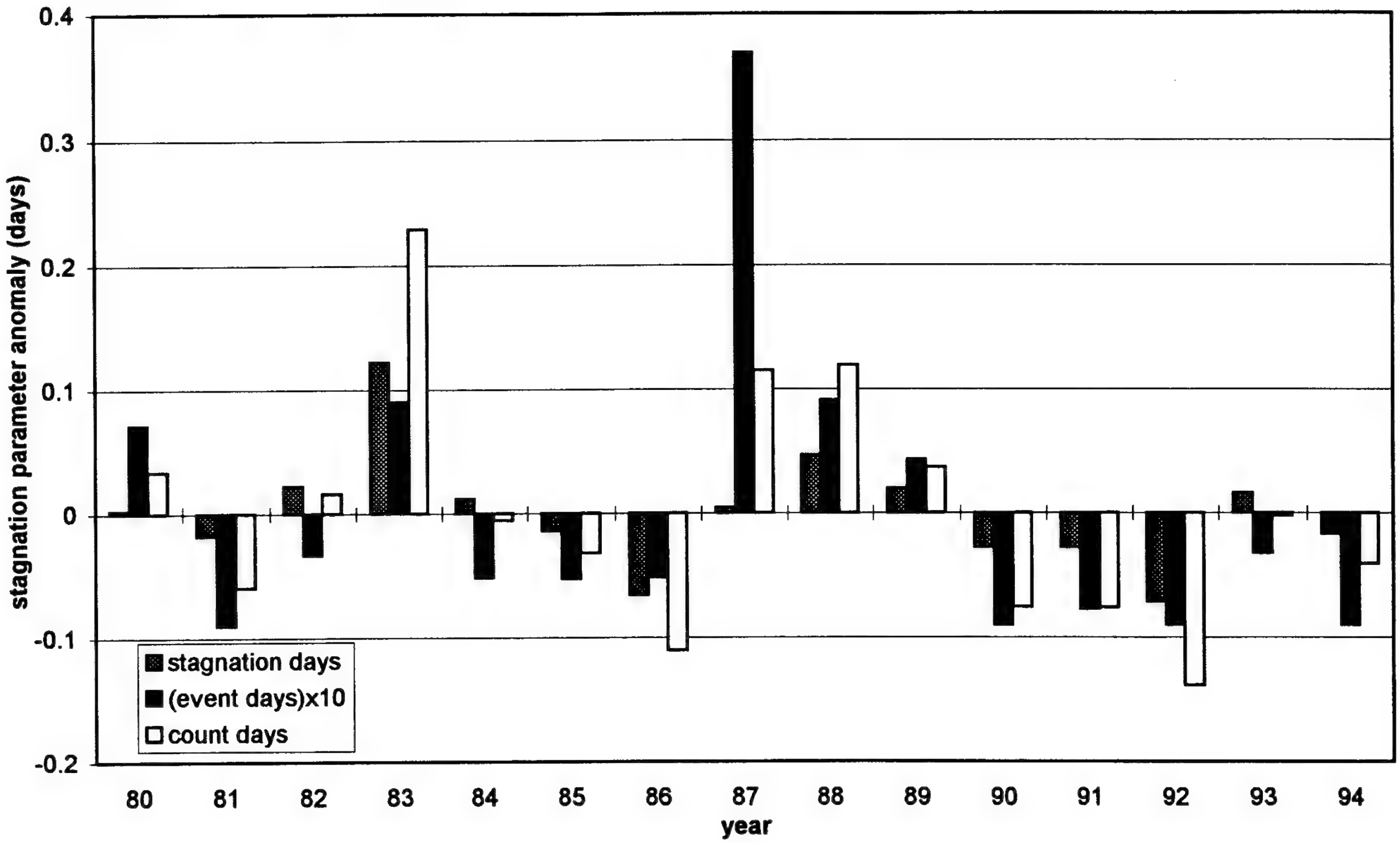


Figure 3.7. Anomalies for stagnation parameters for each ozone season (June-August) in the 15-year study period averaged over all sites.

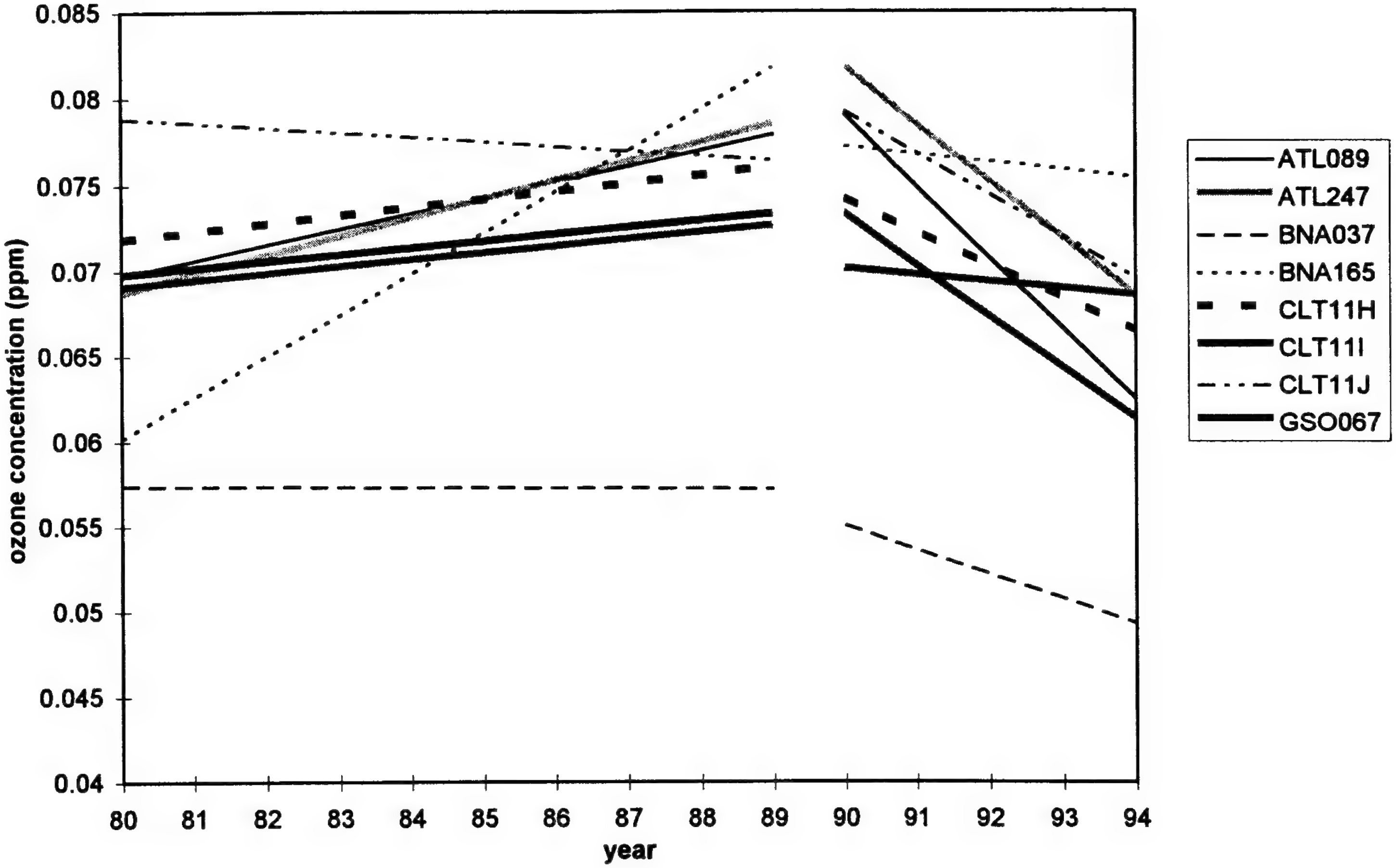


Figure 3.8. Trends in ozone concentration by site. Notice that the slopes are generally positive during the 1980s and negative during the 1990s.

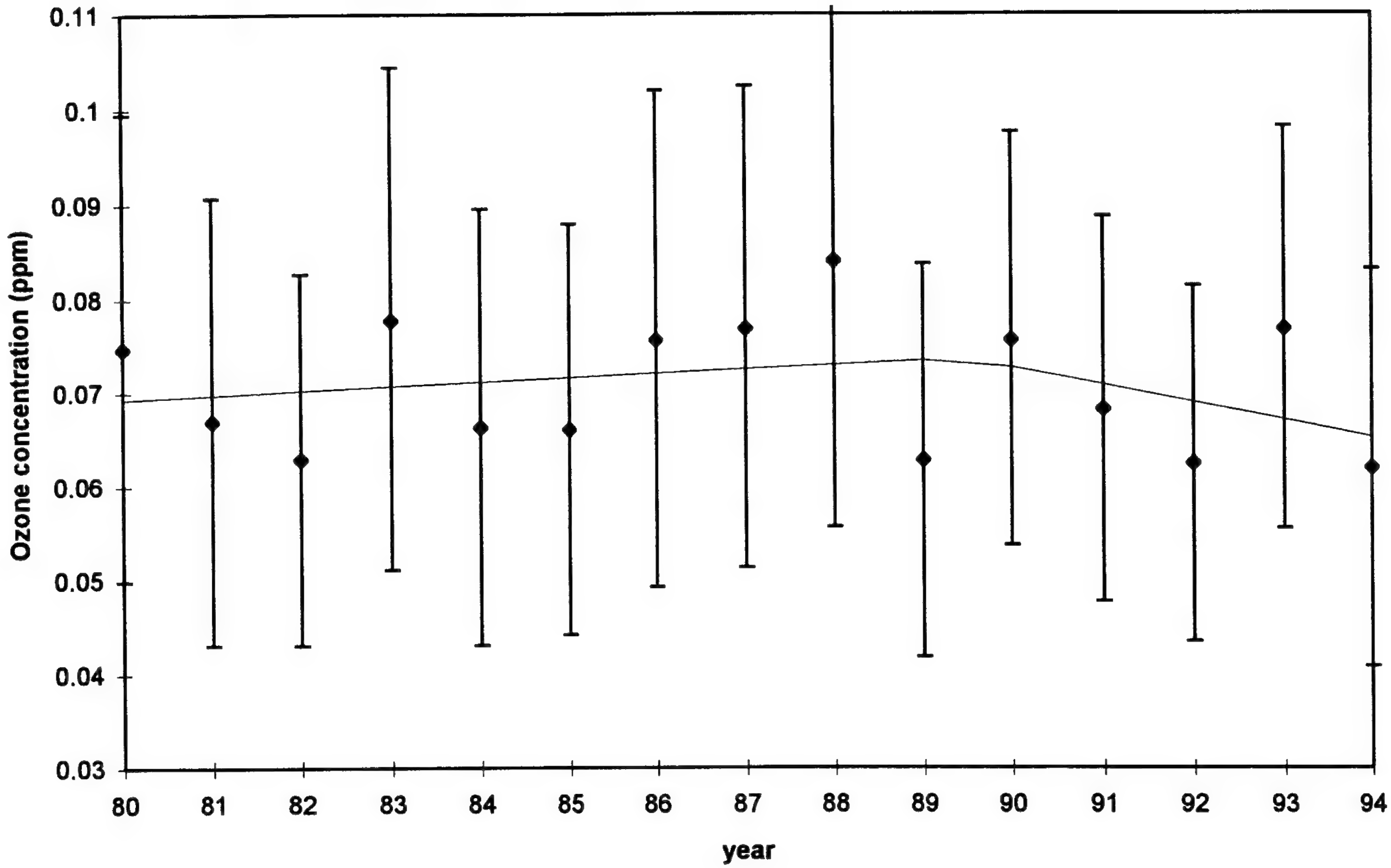


Figure 3.9. Trend in regionally averaged daily maximum ozone concentration by decade. The trend for the 1980s is +0.45 ± 0.83 ppb/yr; that for the 1990s is -1.87 ± 2.34 ppb/yr.

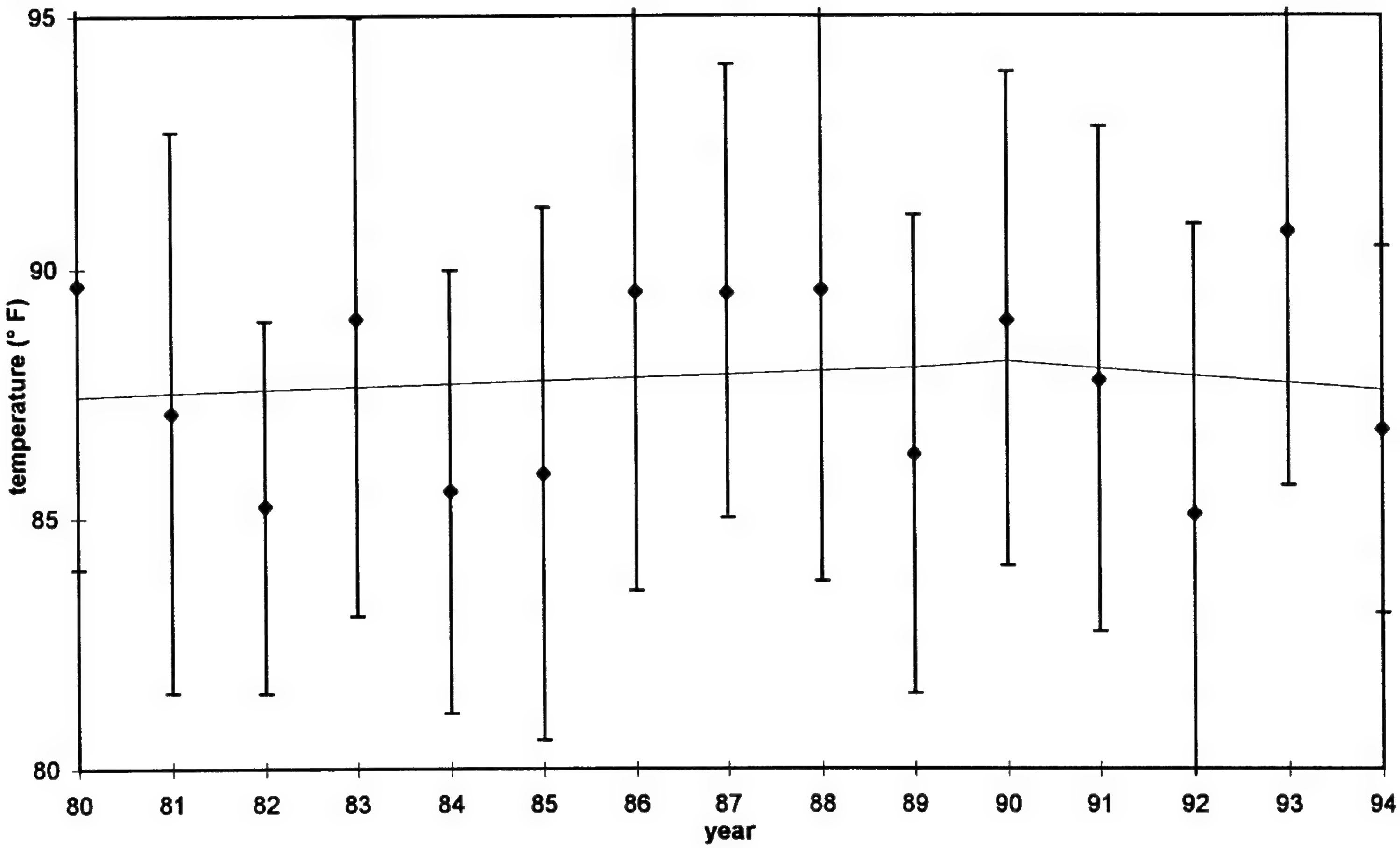


Figure 3.10. Trend in regionally averaged daily maximum temperature by decade.
The trend during the 1980s was +0.06 ± 0.22 °F/yr; that for the 1990s was -0.14 ± 0.78 °F/yr.

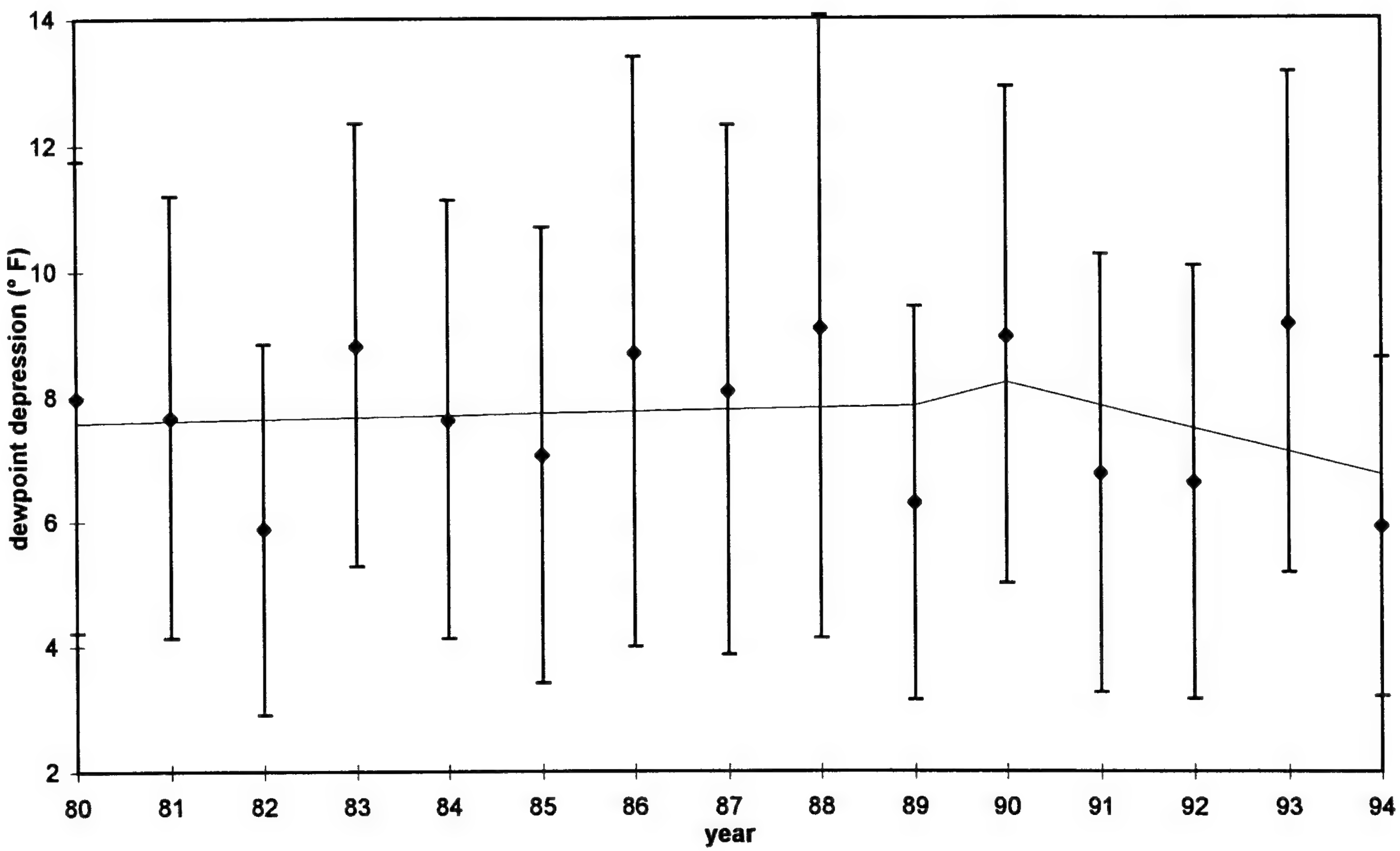


Figure 3.11. Regionally averaged trend in average daily dewpoint depression by decade. The trend during the 1980s was +0.03 ± 0.12 °F/yr; that for the 1990s was -0.37 ± 0.50 °F/yr.

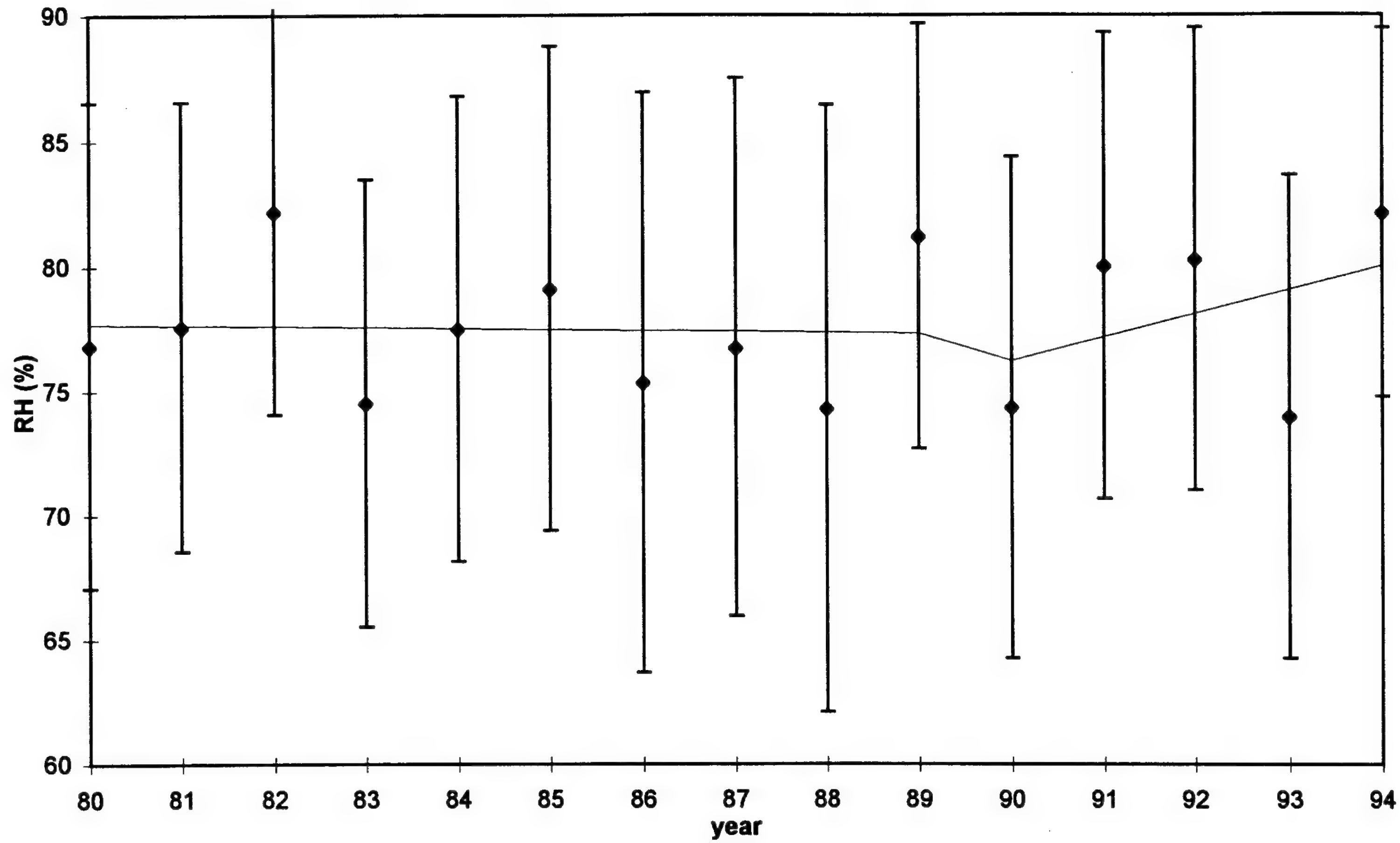


Figure 3.12. Regionally averaged trend in average daily relative humidity by decade.
The trend during the 1980s was -0.04 ± 0.31 %/yr; that for the 1990s was +0.96 ± 1.25 %/yr.

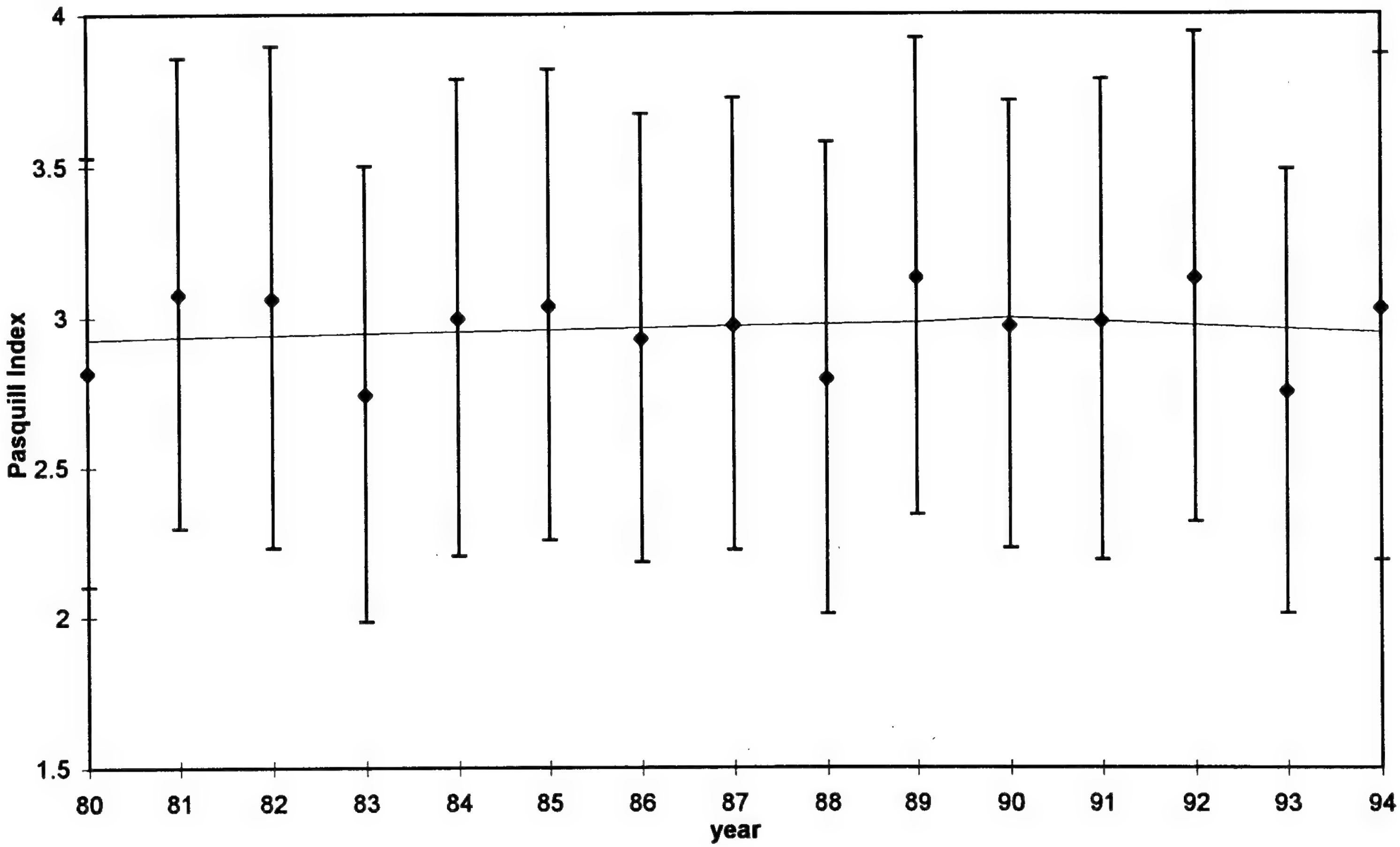


Figure 3.13. Regionally averaged trend in daily minimum Pasquill Index by decade. The trend during the 1980s was +0.006 ± 0.015; that during the 1990s was -0.012 ± 0.050.

CHAPTER 4. MODEL DEVELOPMENT TO FORECAST OZONE

4.1. INTRODUCTION

Ambient concentrations of ozone (O_3) are affected by the variability of both chemical and physical parameters. An effective O_3 control strategy requires monitoring both the chemical precursors to O_3 and the physical (meteorological) parameters that affect its formation, as well as modeling the affect these external influences have on ambient O_3 concentrations. Many researchers (Kelly and Gunst, 1990; Kleinman, et al., 1994; Logan, et al., 1981; Logan, 1985; Logan, 1989; Mathur, 1994; Olszyna, et al., 1994; Penkett, 1991; Sillman, et al., 1990; Sillman, et al., 1993; Trainer, et al., 1987; Trainer, et al., 1991; Venkatram, 1994) have demonstrated that monitoring (and accurately modeling) photochemical precursors to O_3 is crucial toward successfully modeling ambient concentrations for O_3. Another modeling approach is to decompose the observed O_3 time series into deterministic and stochastic components; the deterministic component represents seasonal variation and long term trend, while the stochastic component represents the white noise of daily fluctuations. Rao and Zurbenko (1996) and Flaum, et al. (1996) present such models and provide evidence that 1%, 55%, and 42% of the variation in the original time series could be attributed to long term trend, seasonal variation, and short term variation (white noise), respectively. Yet another (and clearly the simplest) approach is simply use today's maximum O_3 concentration to forecast tomorrow's maximum O_3 concentration. Robeson and Steyn (1990) and Clark and Karl (1982) present variations of such persistence forecasts. Feister and Balzer (1991) demonstrated that the previous day's ozone concentration was the most important predictor of ozone concentration. That is, so-called "persistence" accounted for 33-46% of the climatological variance in ozone concentration (Feister and Balzer, 1991).

It is important, as one component of a comprehensive O_3 control strategy, to quantify the affect that variability in meteorological parameters has on O_3 formation so that improved forecasts can be made for the concentration of O_3 based on meteorological fluctuations. Many researchers have made attempts to model the effect of meteorological fluctuations on O_3 concentration, generally using multiple regression techniques. Clark and Karl (1982) developed such a model, regressing daily maximum ozone concentration against thirty five prognostic meteorological parameters, length of back trajectories, and three air quality indicators. Karl (1979) and Wolf and Lioy (1978) also present similar models, using fewer prognostic variables. Robeson and Steyn (1990) found that a bivariate temperature and persistence based regression model performed better than a univariate deterministic/stochastic model developed by Horowitz and Barakat (1979). The model presented here is regression model similar to the temperature and persistence model developed by Robeson and Steyn (1990). The model presented here differs in that it is developed for the Southeast US region (not site specific) and that it adds more explanatory parameters in the final model fit. A model fit using meteorological parameters is chosen because meteorological variations that lead to O_3 exceedences are relatively short term in duration when compared to the overall trend in O_3 concentration. As a result, modeling the most interesting days (i.e., exceedence days) should be best accomplished using a model that performs best on these short term variations.

4.2. DATA RETRIEVAL

Multiple regression analysis was used to develop models to forecast daily maximum O_3 concentration for each of nine sites representing urban and semi-urban locations in five different Metropolitan Statistical Areas (MSAs) in the Southeast United States. A complete description of the sites used is given in Section 2.2. Meteorological parameters (as defined in Section 2.4) were input as explanatory variables, and the previous day's O_3 concentration was used to reduce the

effect of autocorrelation on the model. Ozone data was retrieved from the Environmental Protection Agency's Aerometric Information Retrieval System (EPA-AIRS) database located in Research Triangle Park, NC. The meteorological data input into the models as explanatory variables were obtained from the Air Force Combat Climatology Center (AFCCC) at Scott Air Force Base, IL. Ozone data was retrieved on an hourly basis, then reduced to daily data, as described in detail in Section 2.3. Meteorological data were also recorded on an hourly basis, then reduced to daily parameters (Section 2.4). Daily averages were computed during the most photochemically active portion of the day (10:00 a.m. - 4:00 p.m. EST) for all of the meteorological parameters. In addition, the daily maximum temperature and the daily minimum Pasquill Stability Index were recorded. A complete description of the O_3 data and the meteorological data used, along with their respective selection criteria, is given in Sections 2.3 and 2.4, respectively.

4.3. STATISTICAL ANALYSIS

The SAS statistical package was used for the data analysis. SAS procedures (PROCs) used in the data analysis included PROC REG to perform initial multiple regression analysis and PROC AUTOREG to perform multiple regression analysis including previous days' values for O_3 concentration in the model fit. PROC UNIVARIATE provided histograms and normal probability plots, which were used to check normality of the residuals.

Two important assumptions inherent in ordinary least squares analysis are homogeneous variance of the residuals and normal distribution of the residuals. If either of these assumptions is not met, then the tests of significance for the regression parameters may not be valid and as a result the model will be corrupted. Plots of model residuals versus predicted values showed random scatter plots, indicating homogeneous variance of the residuals. Histograms produced using PROC

UNIVARIATE were sharply peaked near the center but had low kurtosis values (generally between 1.0 and 2.0); thus problems regarding the normality of residuals were not suspected.

Autocorrelation is a phenomenon in model development in which the previous value of the predictand is a good (in severe cases, the best) predictor for the current value of the predictand. Therefore, the resultant model does not fit well without input of the previous value of the predictand. The Durbin-Watson statistic is a measure of the amount of autocorrelation present in the data set; a data set free of autocorrelation will have a Durbin-Watson statistic near 2.0. Autocorrelation was found to be present in the data set when the explanatory variables (meteorological variables) alone were input into the model developed using PROC REG (i.e., the previous day's O_3 was NOT fit into the model). Without the previous days' O_3 concentration included in the model, the Durbin-Watson statistic was somewhat low (range 1.1 to 1.4), indicative of autocorrelation in the data set. However, previous values of the predictand may be included in the model development using PROC AUTOREG. Models fit using PROC AUTOREG had Durbin-Watson statistic values ranging from 2.03 to 2.08, very near the desired value of 2.0. Whether ten previous days' values for O_3 concentration or only the preceding day's O_3 concentration was included in the model, the Durbin-Watson statistic remained very close to 2.0, indicating that using only *one* previous day's value for O_3 concentration was sufficient to remove the effects of autocorrelation.

4.4. STATISTICAL MODEL

From the analysis in Section 3.2.1., it was determined that the months of June, July, and August best defined the "ozone season". The analysis presented in this chapter is based only on the three month ozone season. Since the analysis in Chapter 3 revealed that the temperature, moisture,

and stability parameters were the meteorological variables best correlated with O_3 concentration, those variables alone were input as explanatory variables in the model development.

Ozone concentration was modeled at each site using linear, quadratic, and exponential models of the following form:

$$Y_t = {}^{1}\beta_0 + {}^{2}\beta_2 MXTMP_t + {}^{3}\beta_3 AVGTMP_t + {}^{4}\beta_4 AVGRH_t + {}^{5}\beta_5 AVGDD_t + {}^{6}\beta_6 AVGTD_t + {}^{7}\beta_7 AVGPAS_t + {}^{8}\beta_8 MINPAS_t + {}^{9}\Sigma C_i D_{it} + {}^{10}\Sigma C_i D_{it} MXTMP_t + {}^{11}\Sigma C_i D_{it} AVGTMP_t + {}^{12}\Sigma C_i D_{it} AVGRH_t + {}^{13}\Sigma C_i D_{it} AVGDD_t + {}^{14}\Sigma C_i D_{it} AVGTD_t + {}^{15}\Sigma C_i D_{it} AVGPAS_t + {}^{16}\Sigma C_i D_{it} MINPAS_t + Z_t \qquad \text{Equation 4.1}$$

Where:

Y_t = maximum daily concentration of O_3 for day t (i.e., $[O_3]$)

$$Z_t = {}^{17}rZ_{t-1} + {}^{18}e_t \qquad \text{Equation 4.2}$$

The subscripted 't' following each term indicates that the term is evaluated on day t (the same day as the forecasted O_3 concentration), except for the term indicating the previous day's O_3 concentration which is followed by 't-1'. The superscripted number preceding each term may be used to identify the term, as listed below:

Term 1 = Overall true intercept of maximum daily $[O_3]$
Term 2 = Effect of daily maximum temperature on $[O_3]$
Term 3 = Effect of average temperature on $[O_3]$
Term 4 = Effect of average relative humidity on $[O_3]$
Term 5 = Effect of average dewpoint temp. depression on $[O_3]$
Term 6 = Effect of average dewpoint temperature on $[O_3]$
Term 7 = Effect of average Pasquill Stability Index on $[O_3]$
Term 8 = Effect of minimum Pasquill Stability Index on $[O_3]$
Term 9 = Effect of each site, represented by dummy variable D_{it} (see below)
Term 10 = Interaction effect between site and daily max. temp
Term 11 = Interaction effect between site and average temp.
Term 12 = Interaction effect between site and average relative humidity
Term 13 = Interaction effect between site and average dewpoint depression
Term 14 = Interaction effect between site and average dewpoint temp.
Term 15 = Interaction effect between site and average Pasquill Index
Term 16 = Interaction effect between site and minimum Pasquill Index

Term 17 = Effect, through the residual correlation, of the previous day's O_3 concentration on $[O_3]$

Term 18 represents the "error" inherent in the measurement of daily maximum $[O_3]$

The model presented is shown in the format of the linear model. The minor modifications given below transform the given model to the quadratic and exponential forms.

When developing a quadratic model, statisticians generally leave the linear terms in the model for any statistically significant quadratic term. Therefore, for the quadratic model, each β_i represents the vector $\beta_i = (\alpha_1 + \alpha_2 TERM_i)$, where *TERM* represents the explanatory parameter being fit in that case. For example,

$$\beta_2 MXTMP_t = (\alpha_1 + \alpha_2 MXTMP_t) MXTMP_t \qquad \text{Equation 4.3}$$

$$\beta_2 MXTMP_t = \alpha_1 MXTMP_t + \alpha_2 MXTMP_t^2 \qquad \text{Equation 4.4}$$

To transform the model as given in Equation 4.1 into the format of the quadratic model, the transformation given in Eqn. 4.3 and Eqn. 4.4 above must be applied to each term in Eqn. 4.1.

The only difference in the exponential model is that the predictand is the natural logarithm of daily maximum ozone concentration on day t. That is, to transform Equation 4.1 into the exponential model, simply take the natural logarithm of Y_t,

That is, $ln(Y_t) = \ldots$

The C's and β's in Equation 4.1 represent regression coefficients determined from ordinary least squares multiple regression analysis, and depict the change in O_3 concentration expected from a unit increase in one variable, assuming all other variables are held constant. The effect of site location is fit into the model using the dummy variable D. D_i has a value of 1 only for the i^{th} site, and has a value of zero for all other sites. As a result, each summation term (i.e., Terms 9-16) in the equations above represents nine terms, one for each site.

In addition to the models presented above, a model based solely on persistence of the daily maximum O_3 concentration from the previous day was used as a baseline to compare the prognostic models against:

Persistence: $Y_t = {}^{1}\beta_0 + {}^{17}\beta_1 Y_{t-1} + {}^{18}e_t$ Equation 4.5

The terms are identified in the same manner as those identified previously.

4.5. RESULTS AND DISCUSSION

The three multivariate models considered gave very similar results; regardless of which model was used, the model fit accounted for just over 50% (R^2=0.53 or 0.54) of the observed variance in daily maximum O_3 concentration. Performance of the multivariate models was much better than a simple persistence-based model alone, which produced a model-explained variance of only R^2=0.31.

Evaluation of the dummy variable interactions in PROC AUTOREG is accomplished by comparing the first eight (in this case) dummy variable interactions to the interactions resulting from the last dummy variable. If the i^{th} interaction is not statistically different from the last interaction, then the i^{th} interaction may be discounted as non-significant and therefore removed from the model. As such, regression coefficient calculations and resultant best model fit differ depending on which site is chosen as the last site (the site to which all others are compared). Each time a new site was chosen as the site to be compared against, there was evidence to suggest that there were statistically significant interactions (at the 1% level) present for one or two variables between it and one or two sites, but the majority of the site interactions could be discounted as nonsignificant at the 1% level. Only ATL089 and CLT119I frequently demonstrated statistically significant interactions with the variables at other sites. Generally speaking, however, the interactions were not statistically significant at the 1% level and could therefore be removed from

the model, resulting in one model fit for the entire region. Upon removal of all of the site terms and site interaction terms from the models, the resultant model fits were not reduced significantly. Figure 4.1 clearly shows that a model fit with all of the interaction terms is nearly identical to a model fit with none of the interaction terms. Since there is not a difference in the respective model fits, the interaction terms may be deleted without sacrificing model performance. Models without site interaction terms still explained over 50% of the variance; R^2 values for the linear, quadratic, and exponential models were 0.50, 0.51, and 0.51, respectively.

The data set was analyzed to test the regression of all possible combinations of parameters in the models above. Parameters that did not demonstrate statistical significance at the 1% significance level were considered not statistically significant and consequently removed from the models. At the 1% significance level, average temperature, average dewpoint temperature depression, and average Pasquill Index could all be removed from each of the three multivariate models (linear, quadratic, and exponential models). In addition to these parameters, average relative humidity and average dewpoint temperature were also found to be statistically insignificant. Although statistical significance indicated that all of these parameters could be removed from each of the models in one step, only one parameter was removed at a time. Removing all of the parameters that initially appear insignificant all at once may result in removal of a parameter that would become more important in accounting for variation in the data set when fewer parameters are present to fit the model. Therefore, the parameter that tested least statistically important in the first model run was removed, then the AUTOREG procedure was allowed to reevaluate the importance of each remaining parameter, repeating the same procedure until all statistically insignificant parameters are removed from the model. Reducing the model in this fashion resulted in leaving the same parameters in each of the multivariate models: daily maximum temperature, average relative humidity, average dewpoint temperature, and minimum

daily Pasquill Index. The R^2 values (0.50, 0.51, and 0.51 for the linear, quadratic, and exponential models, respectively) in the final model fit were only slightly lower than those before removing the parameters that tested statistically insignificant.

The Akaike Information Criterion (AIC) and the Schwartz Bayesian Criterion (SBC) are often used to evaluate models to determine which model is the most efficient model for a given data set. Both statistics represent a balance between the number of parameters fit and the amount of increase in the R^2 value generated by adding additional terms to the model. The model with the lowest AIC or SBC represents the best balance between number of parameters in the model and resulting R^2 value. Note however, that direct comparison cannot be made across model types in this case because the dependent variable for the exponential model has been transformed; these statistics only allow comparison between variations of model fit to a given dependent variable. Both statistics show that the best overall fit of the models occurs when all of the interaction terms are included. However, we have shown that there is minimal decrease in R^2 values when the site interaction terms are removed, and practical considerations warrant their removal in order to simplify the model and create a regional model. Using the AIC and SBC methods to determine the most efficient models, while considering only models without the site interaction terms, the linear model with the most efficient fit requires five meteorological parameters. The quadratic model with the most efficient fit requires ten meteorological parameters. However, the exponential class of models allows a model with only four meteorological parameters. That is, an exponential model including only terms for daily maximum temperature, average relative humidity, average dewpoint temperature, and minimum Pasquill Index fit as good as a linear model with five parameters or a quadratic model with ten parameters. Therefore, even though the R^2 were nearly the same for all of the multivariate models at all stages of model reduction, the exponential model forecasts daily maximum O_3 concentration best for this data, because it is able to explain the variance in O_3

concentration data set efficiently with fewer parameters. The resultant best fit models for each class are given below:

<u>Linear</u> (Equation 4.6)

$$O_3 = -0.0969 + 0.0025(MXTMP_t) + 0.0007(AVGRH_t) - 0.0015(AVGTD_t) + 0.0012(AVGDD_t) - 0.0049(MINPAS_t) + Z_t$$

Where $Z_t = 0.4559[O_{3\ t-1}(\text{actual}) - O_{3\ t-1}(\text{forecasted})]$

<u>Quadratic</u> (Equation 4.7)

$$O_3 = 0.1971 + 0.000036(MXTMP_t)^2 - 0.000026(AVGTD_t)^2 + 0.000030(AVGDD_t)^2 + 0.0028(AVGPAS_t)^2 + 0.00083(MINPAS_t)^2 - 0.00369(MXTMP_t) - 0.00106(AVGTMP_t) + 0.00286(AVGTD_t) - 0.02588(AVGPAS_t) - 0.00973(MINPAS_t) + Z_t$$

Where $Z_t = 0.4542[O_{3\ t-1}(\text{actual}) - O_{3\ t-1}(\text{forecasted})]$

<u>Exponential</u> (Equation 4.8)

$$\log(O_3) = -4.582 + 0.0390(MXTMP_t) + 0.0046(AVGRH_t) - 0.0255(AVGTD_t) - 0.0729(MINPAS_t) + Z_t$$

Where $Z_t = 0.4852[O_{3\ t-1}(\text{actual}) - O_{3\ t-1}(\text{forecasted})]$

Each model predicts the ambient O_3 concentration for the Southeast United States to be higher with higher daily maximum temperature, higher average mid-day relative humidity, lower mid-day dewpoint temperature, and more mid-day instability. The Z_t term in the models uses the residuals (errors) from the previous day's forecast to help refine the current day's forecast. As such, it is essentially "learning" from its errors on the previous day's forecast to improve the current day's forecast. A sample model fit using the regional exponential model is presented in

Figure 4.2. The model performs relatively well with respect to predicting the short term trend of O_3 concentration, but the magnitude of very high O_3 peaks is not modeled accurately. For this reason, we wished to verify the conclusion drawn earlier (i.e., a *regional* model would perform sufficiently; *site specific* models would not be necessary). A site-specific model was fit for one of the Charlotte sites (CLT119I) that demonstrated slightly significant site interaction terms, as discussed at the beginning of this section. Figure 4.3 compares this site-specific model fit with actual data for CLT119I during the 1988 ozone season. Comparison of Figures 4.2 and 4.3 verifies that the site specific model does not perform differently from the regional model; trends are forecasted well, but the magnitude of extreme O_3 concentrations is not accurately predicted by either model. Model performance could most likely be improved by including terms to explain the variation in O_3 concentration that would result from fluctuations in the concentrations of O_3 precursors.

Model sensitivity calculations were performed using the regional exponential model to determine what combination of meteorological parameters would result in an O_3 concentration of 0.120 ppmv, the NAAQS for the pollutant. These calculations were performed simplifying Equation 4.8 with two assumptions. First, we assume the residual error from the previous model run can be ignored (i.e., $Z_t = 0$). Second, since the expected range for the minimum Pasquill Index is very small, let it remain fixed at the climatological average value of 3.0. The resulting equation allows us to examine the three-way model-forecasted interaction between the remaining meteorological parameters that may lead to O_3 exceedence by simply inserting expected ranges of values for the parameters that may typically occur during summer months in the Southeast U.S.:

$$\log(0.120) = -4.582 + 0.0390(MXTMP_t) + 0.0046(AVGRH_t) - 0.0255(AVGTD_t) - 0.0729(3.0) \qquad \text{Equation 4.9}$$

Simultaneous solution of Eqn. 4.9 by setting two of the parameters at various predetermined levels and solving for the third parameter in each case results in a plane in three dimensional space (see Figure 4.4) for which all points represent the combination of meteorological parameters which result in an O_3 concentration of 0.120 ppmv. Any point in the space above (below) the plane in Figure 4.4 will have an ozone concentration in exceedence of (compliance with) the NAAQS for O_3. Solutions to Eqn. 4.9 are given in Table 4.1, in which model solutions for daily maximum temperature were computed, given various predetermined levels of relative humidity and dewpoint temperature. Notice that, for a given dewpoint temperature, lower air temperatures allow O_3 concentration = 0.120 ppmv as the relative humidity increases. That is, it is "easier" to maintain compliance with the NAAQS when the relative humidity is *lower*. Similarly, for a given relative humidity, lower air temperatures allow O_3 concentration = 0.120 ppmv as the dewpoint temperature decreases; it is "easier" to maintain compliance with the NAAQS when the dewpoint temperature is *higher*. Furthermore, note that some of the values in the table are simply model idealizations and cannot happen in the physical atmosphere. For example, given dewpoint temperature of 50°F and relative humidity of 100%, the model-calculated daily maximum temperature resulting in O_3 concentration of 0.120 ppmv is 89.6°F; clearly the ambient temperature cannot be that high with dewpoint temperature of 50°F and RH=100%. The table may be used only to obtain a relative understanding of the three way interaction between the parameters, irregardless of the physical possibility of the mathematical solutions to the model existing in the ambient environment.

4.6. CONCLUSIONS

Developing a model to accurately predict ambient O_3 concentrations is difficult to accomplish because there are many chemical and physical factors that affect the variation of O_3 at

a given site. The effect of meteorology is believed to be a very important factor that leads to alteration of ambient O_3 concentrations. Particularly at urban and semi-urban sites, where concentrations of the precursors to O_3 formation are in a more chemically reactive state, changing meteorological conditions may have a large effect on the resultant mix of atmospheric oxidants, of which O_3 raises the most concern. From a policy perspective, the problem is further compounded by the fact that forecasts of meteorological variables are not accurate beyond a few days and forecasts of concentrations of precursors to O_3 are not readily available. Three different classes of models (linear, quadratic, and exponential) to predict daily maximum ambient O_3 concentrations were developed based on meteorological parameters using ordinary least squares regression. Fifteen years worth of "Ozone season" (June, July, and August) data representative of nine sites in five different metropolitan statistical areas (MSAs) in the Southeast United States were analyzed. Autocorrelation was found to be present in the data, indicating that the previous day's daily maximum O_3 concentration was a good predictor of the current day's forecasted daily maximum O_3 concentration. A persistence-based model alone accounted for only about 31% of the variation (R^2 values of 0.31 and 0.32, depending upon which class of model was being evaluated) in the observed daily maximum O_3 concentration. Interactions between the sites were, in general, determined not to be statistically significant; those interactions that did test statistically significant were determined not to make enough significance from a practical standpoint since they only increased R^2 values marginally. The best model was determined by examining model fit statistics (R^2 values) and model efficiency statistics (AIC and SBC statistics). According to the AIC and SBC statistics, the linear and quadratic models required more parameters to have the most efficient fit; the exponential model required the fewest parameters. The best fit reduced exponential model predicted daily maximum O_3 concentrations using daily maximum temperature, average relative humidity, average dewpoint temperature, and minimum Pasquill Stability Index, along with the

previous day's maximum O_3 concentration. Model sensitivity analysis showed that ozone concentration is most sensitive to fluctuations in daily maximum temperature, quite sensitive to changes in dewpoint temperature, and least sensitive to changes in relative humidity.

A better model to predict ambient O_3 concentrations could be developed if parameters to represent the concentration of chemical precursors (NO_X and VOCs) to O_3 were included in the model. Reducing the model developed here from a site specific model to a regional model was a simplification that may be better justified in the absence of the chemical precursor data. Inclusion of NO_X and VOCs data would result in a much more robust model since a large amount of the variability in O_3 concentration would likely be explained by the variation of the chemical precursors. However, site specific models may be more appropriate when including data to parameterize the chemical precursors to O_3 since the data will vary widely between sites.

Table 4.1. Three way simultaneous solution of the regional model developed to forecast ozone concentration. Daily maximum temperature (°F) is given as a function of various predetermined levels of dewpoint temperature and relative humidity. Each combination of the three meteorological variables presented in the table will result in a model forecasted ozone concentration of 0.120 ppmv.

Relative Humidity (%)	**Dewpoint temperature (°F)**							
	45	**50**	**55**	**60**	**65**	**70**	**75**	**80**
55	91.7	94.9	98.2	101.5	104.7	108.0	111.3	114.5
60	91.1	94.3	97.6	100.9	104.2	107.4	110.7	114.0
65	90.5	93.8	97.0	100.3	103.6	106.8	110.1	113.4
70	89.9	93.2	96.4	99.7	103.0	106.2	109.5	112.8
75	89.3	92.6	95.8	99.1	102.4	105.7	108.9	112.2
80	88.7	92.0	95.3	98.5	101.8	105.1	108.3	111.6
85	88.1	91.4	94.7	97.9	101.2	104.5	107.7	111.0
90	87.5	90.8	94.1	97.3	100.6	103.9	107.2	110.4
95	86.9	90.2	93.5	96.8	100.0	103.3	106.6	109.8
100	86.4	89.6	92.9	96.2	99.4	102.7	106.0	109.2

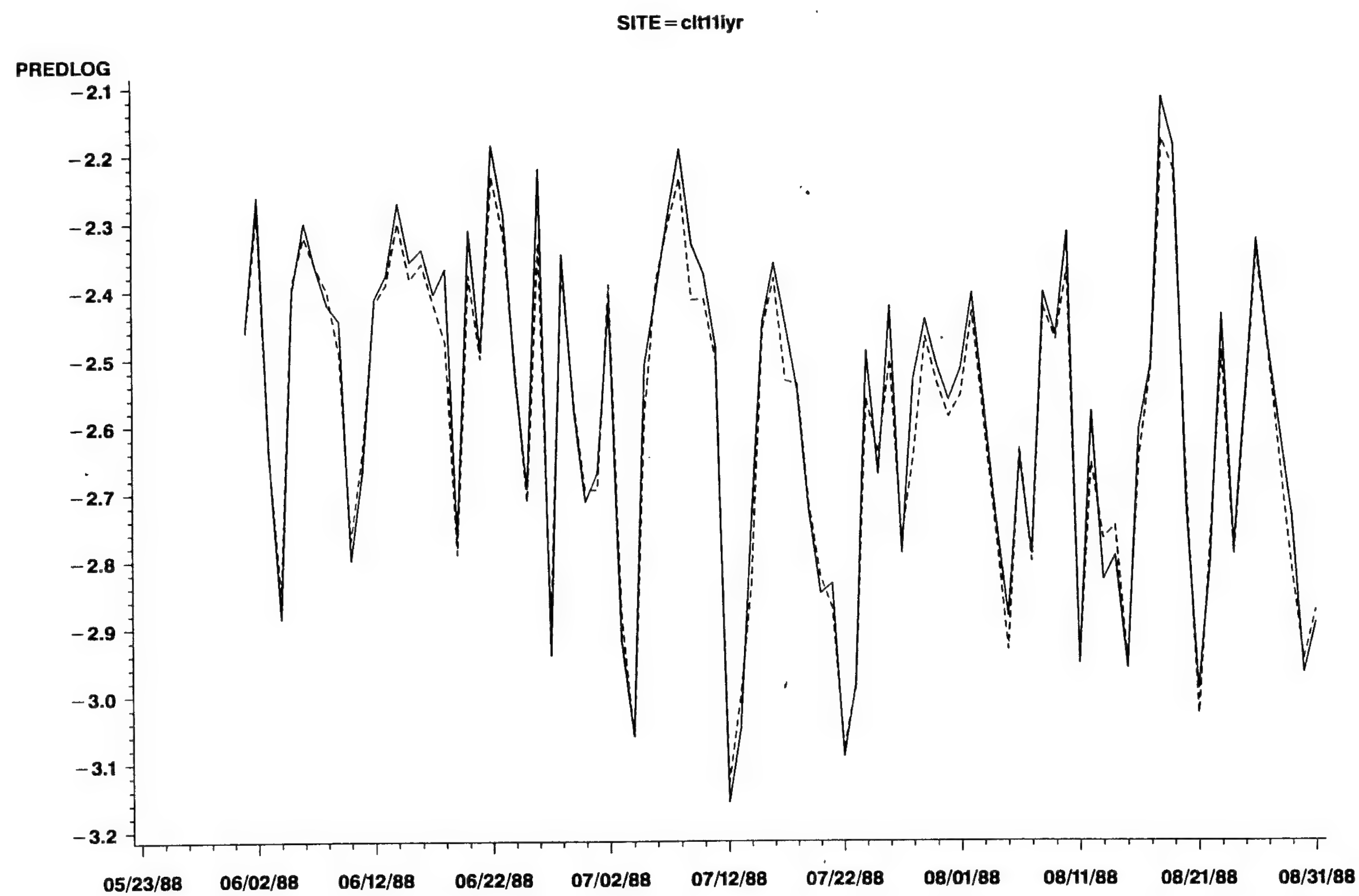


Figure 4.1. Comparison of a model fit including all site interaction terms (solid line) versus one fit not including any site interaction terms (dashed line). The data is for the 1988 ozone season for a Charlotte site (CLT119I). Note that the y-axis is presented on a logarithmic scale, not directly in ozone concentration. For example, -2.5 represents an ozone concentration of exp(-2.5) = 0.082 ppm.

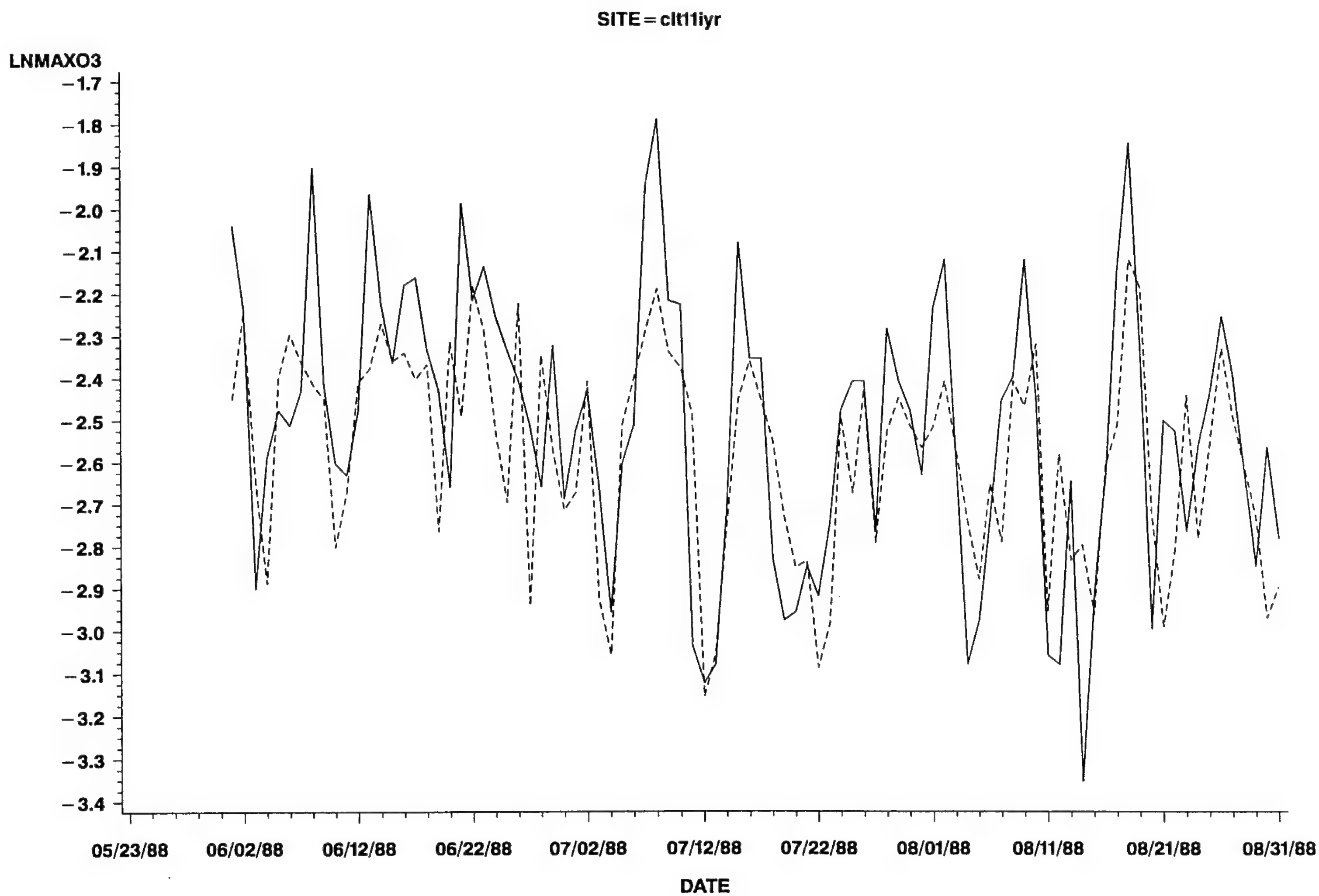


Figure 4.2. Exponential model fit (dashed line) compared with observed data (solid line) for the model developed for *regional forecasting*. The data is for the 1988 ozone season for a Charlotte site (CLT119I). Note that the y-axis is presented on a logarithmic scale, not directly in ozone concentration. For example, -2.5 represents an ozone concentration of exp(-2.5) = 0.082 ppm.

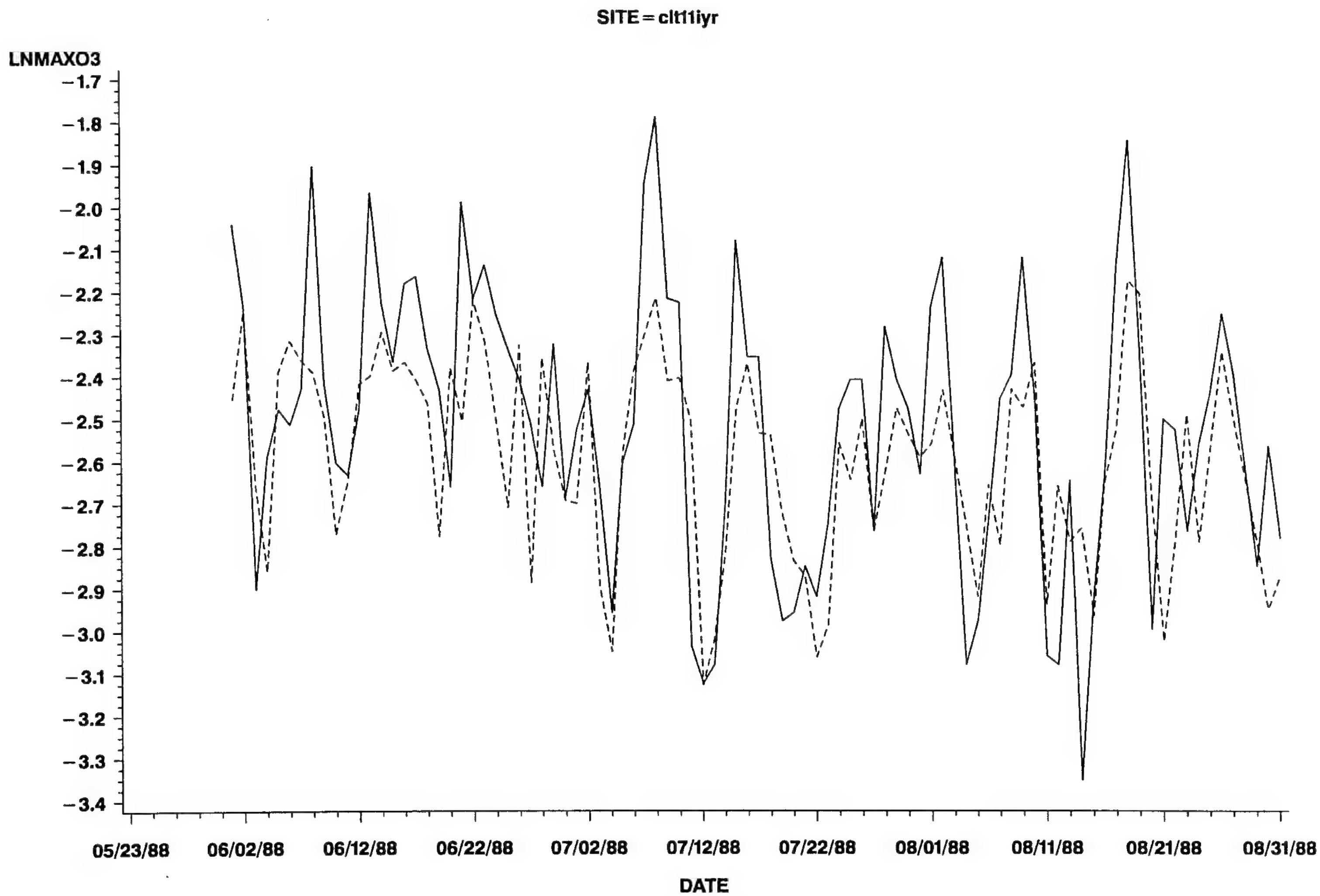


Figure 4.3. Exponential model fit (dashed line) compared with observed data (solid line) for the model developed for *site-specific forecasting only*. The model was developed for a Charlotte, NC site (CLT119I) and the data is for the 1988 ozone season for the same site. Note that the y-axis is presented on a logarithmic scale, not directly in ozone concentration. For example, -2.5 represents an ozone concentration of exp(-2.5) = 0.082 ppm.

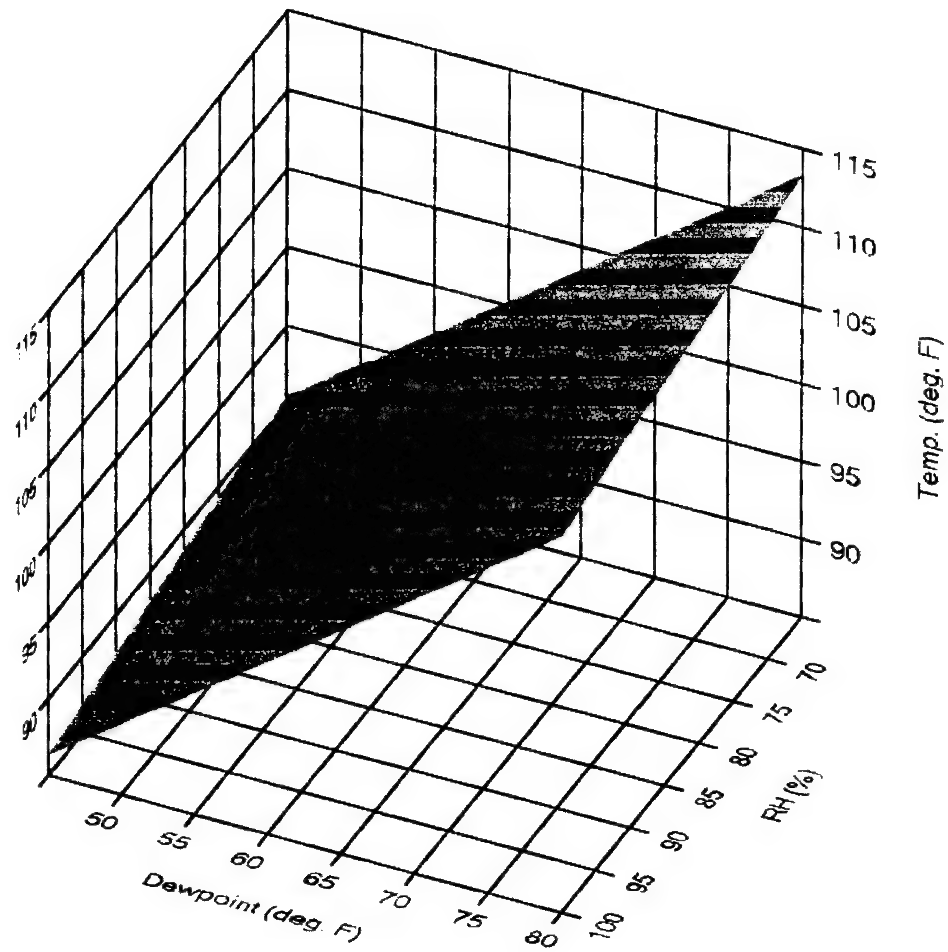


Figure 4.4. Model idealization of the three way interaction between relative humidity, dewpoint temperature, and ambient air temperature values which lead to ozone concentration = 0.120 ppmv. Simultaneous solution of the model will result in a plane in three dimensional space. Any point in the space above (below) the plane will have an ozone concentration in exceedence of (compliance with) the NAAQS for O_3.

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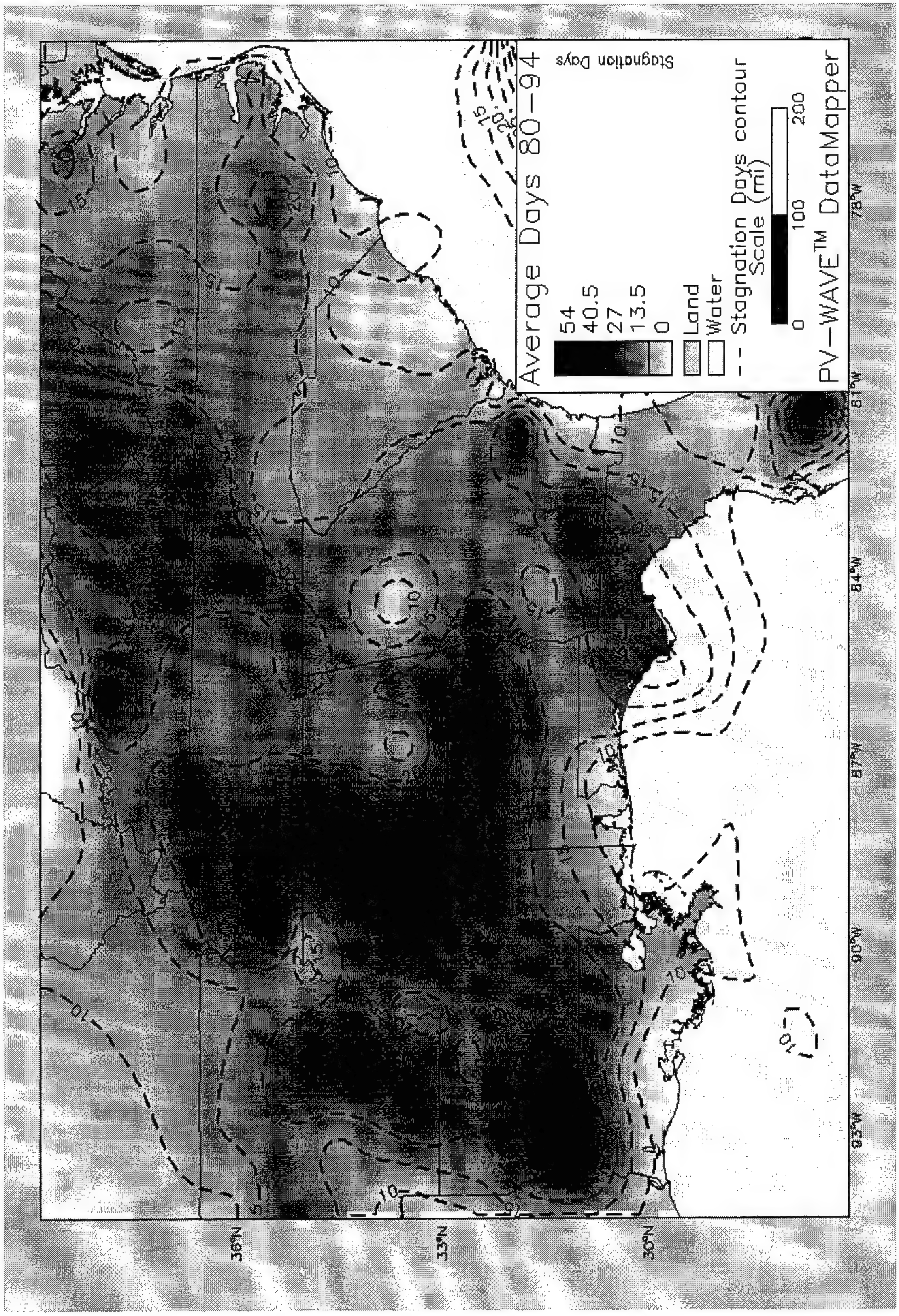
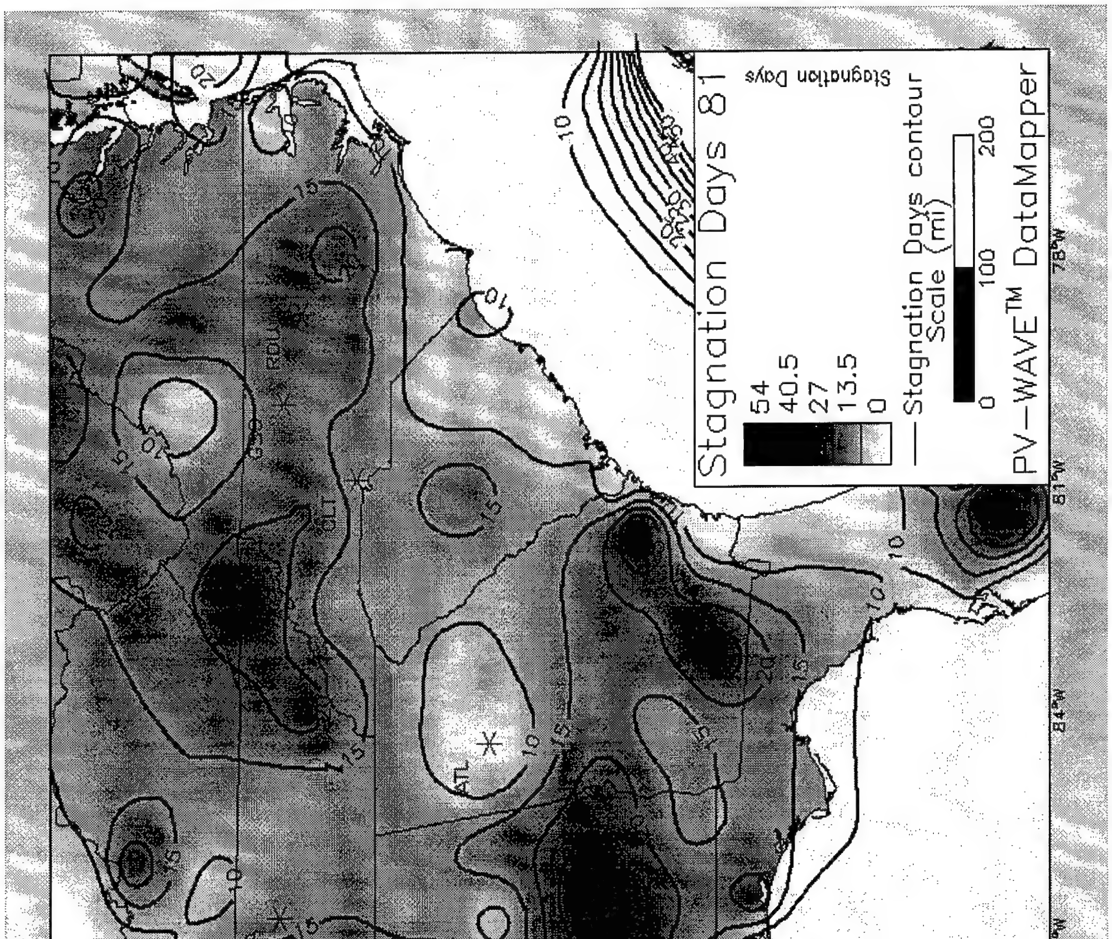
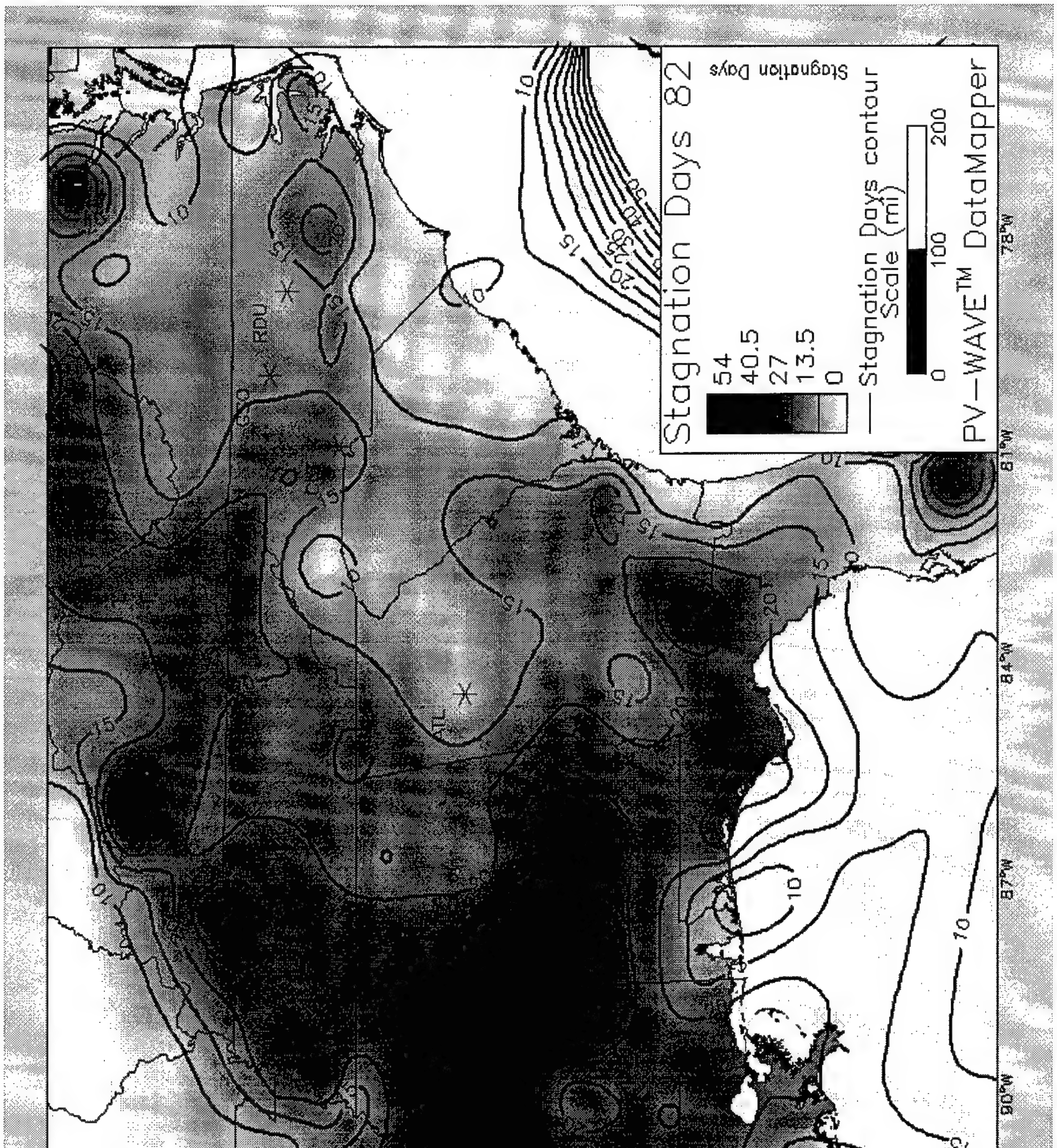
APPENDIX 1

Regional High Pressure Stagnation Maps

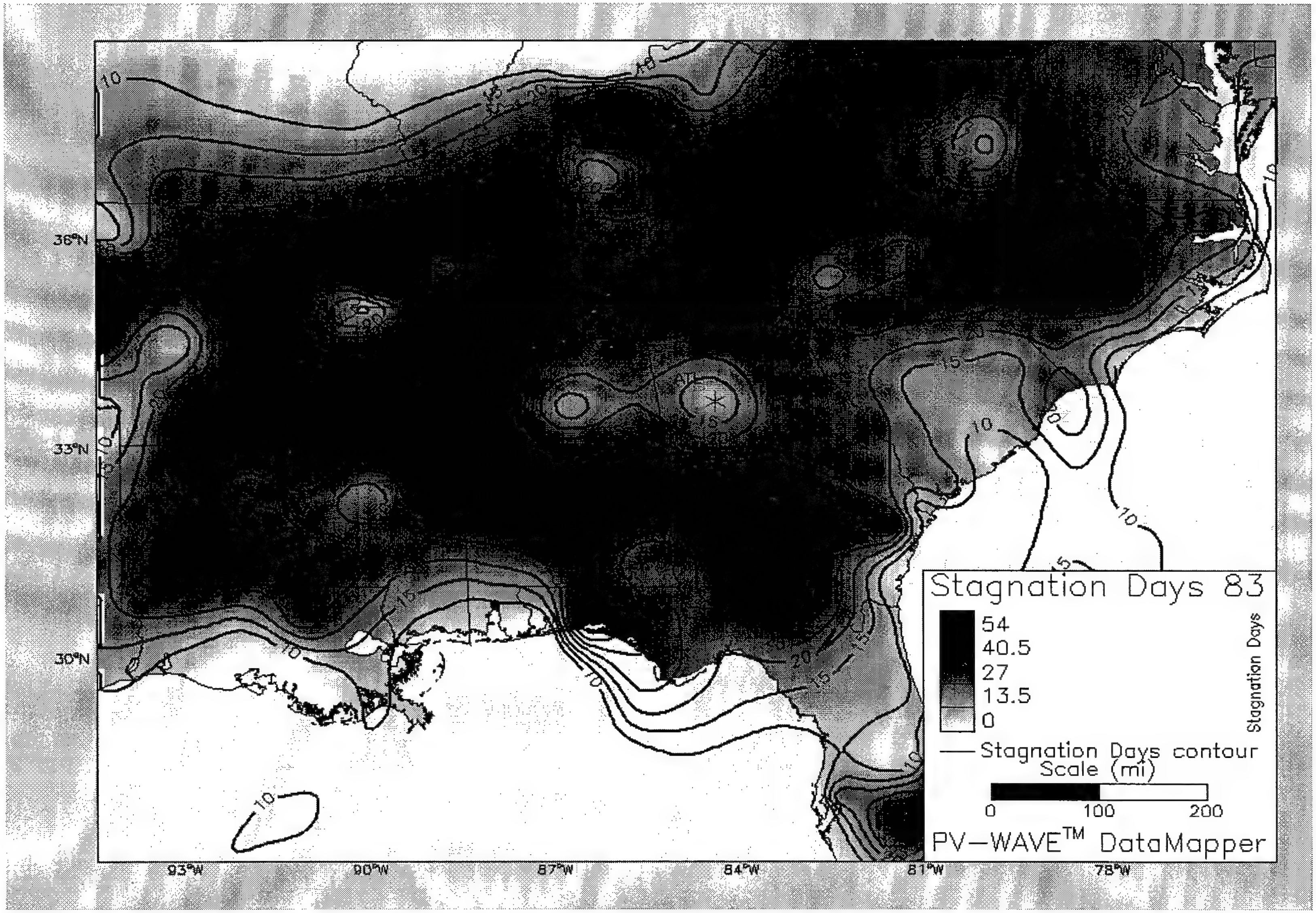


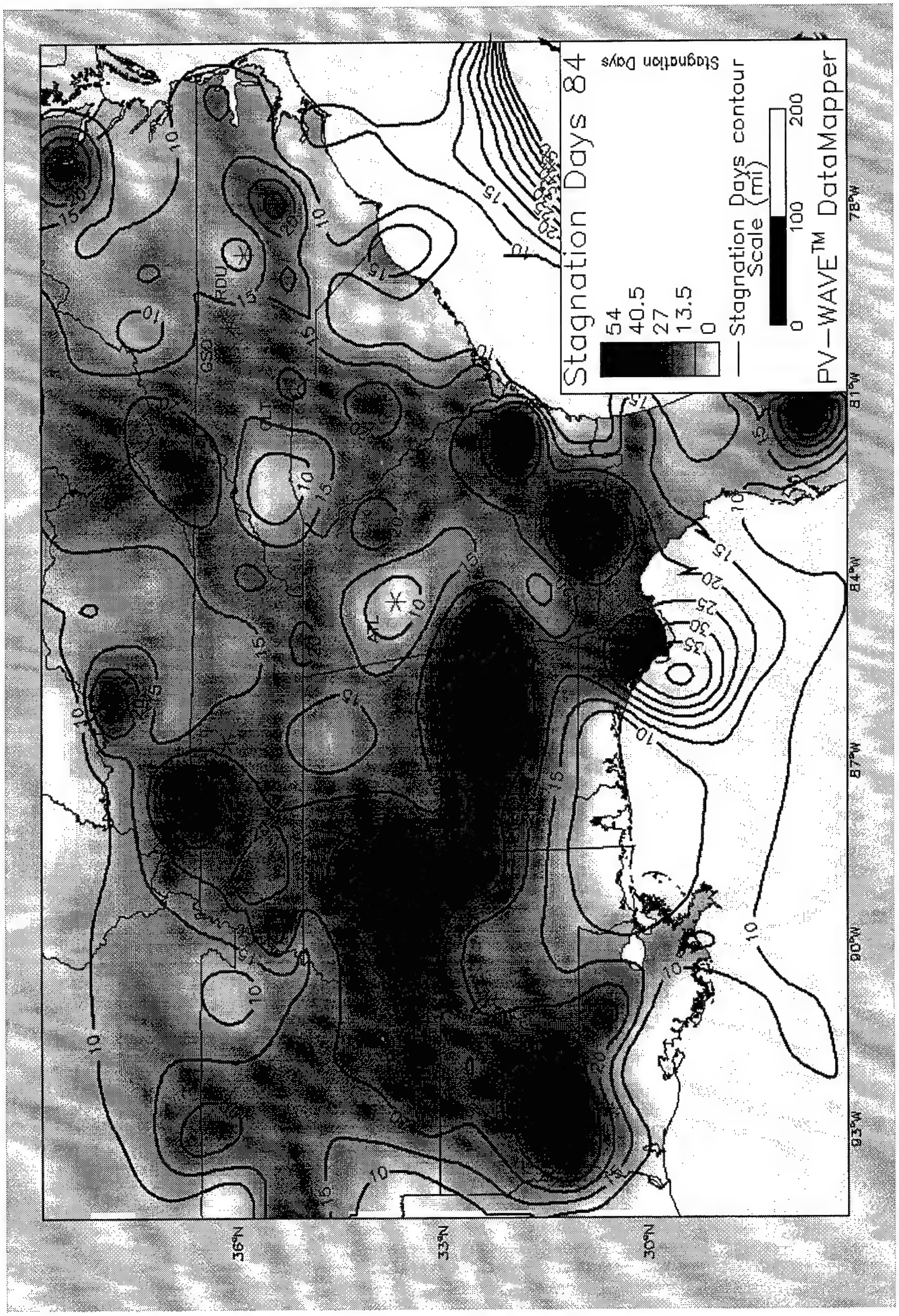
Average Days 80−94
54
40.5
27
13.5
0
Land
Water
Stagnation Days contour
Scale (mi)
0
100
200
PV−WAVE™ DataMapper
36°N
33°N
30°N
93°W
90°W
87°W
84°W
81°W
78°W

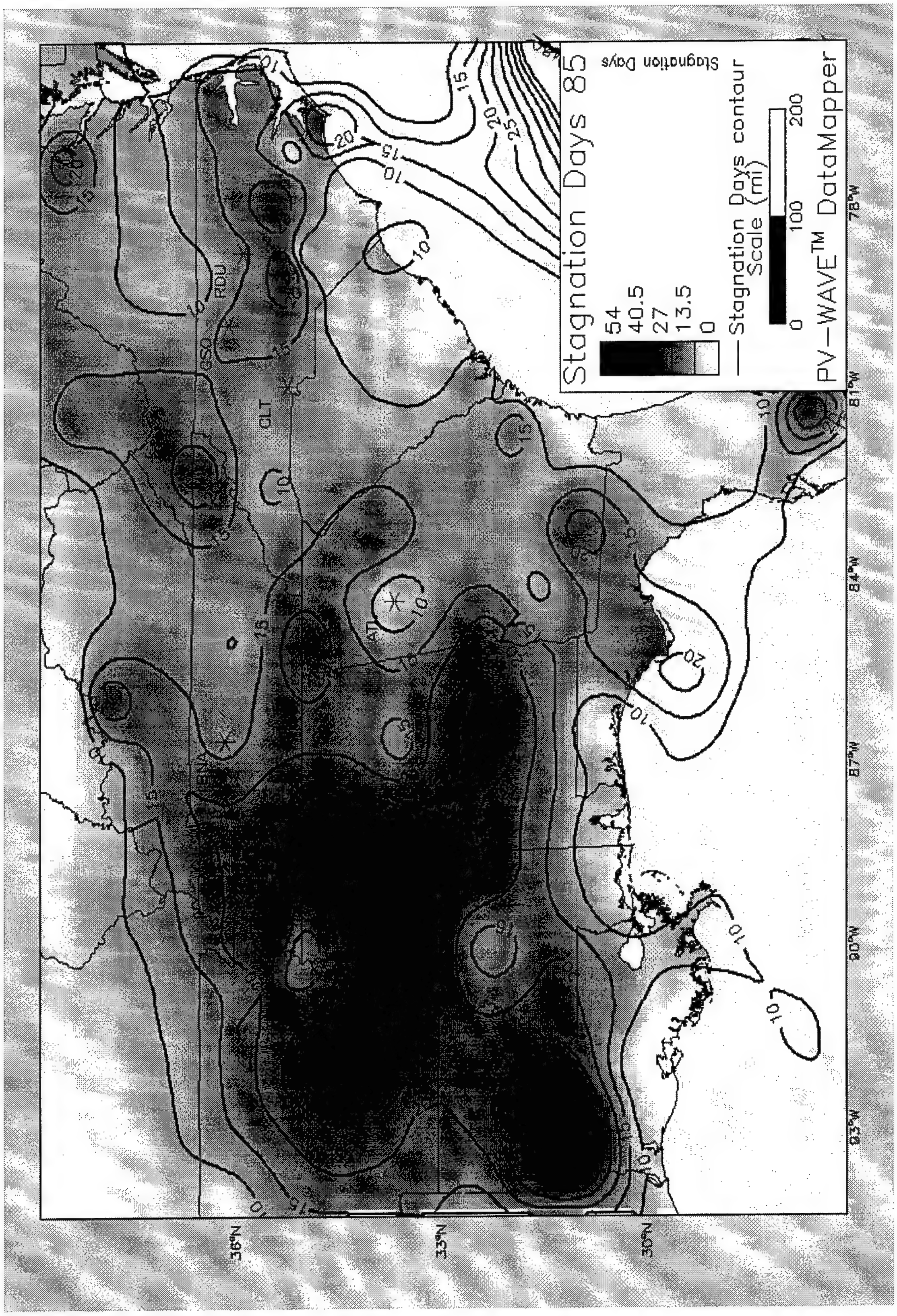

Stagnation Days 81
54
40.5
27
13.5
0
Stagnation Days contour
Scale (mi)
0 100 200
PV—WAVE™ DataMapper
36°N
33°N
30°N
93°W
90°W
87°W
84°W
81°W
78°W



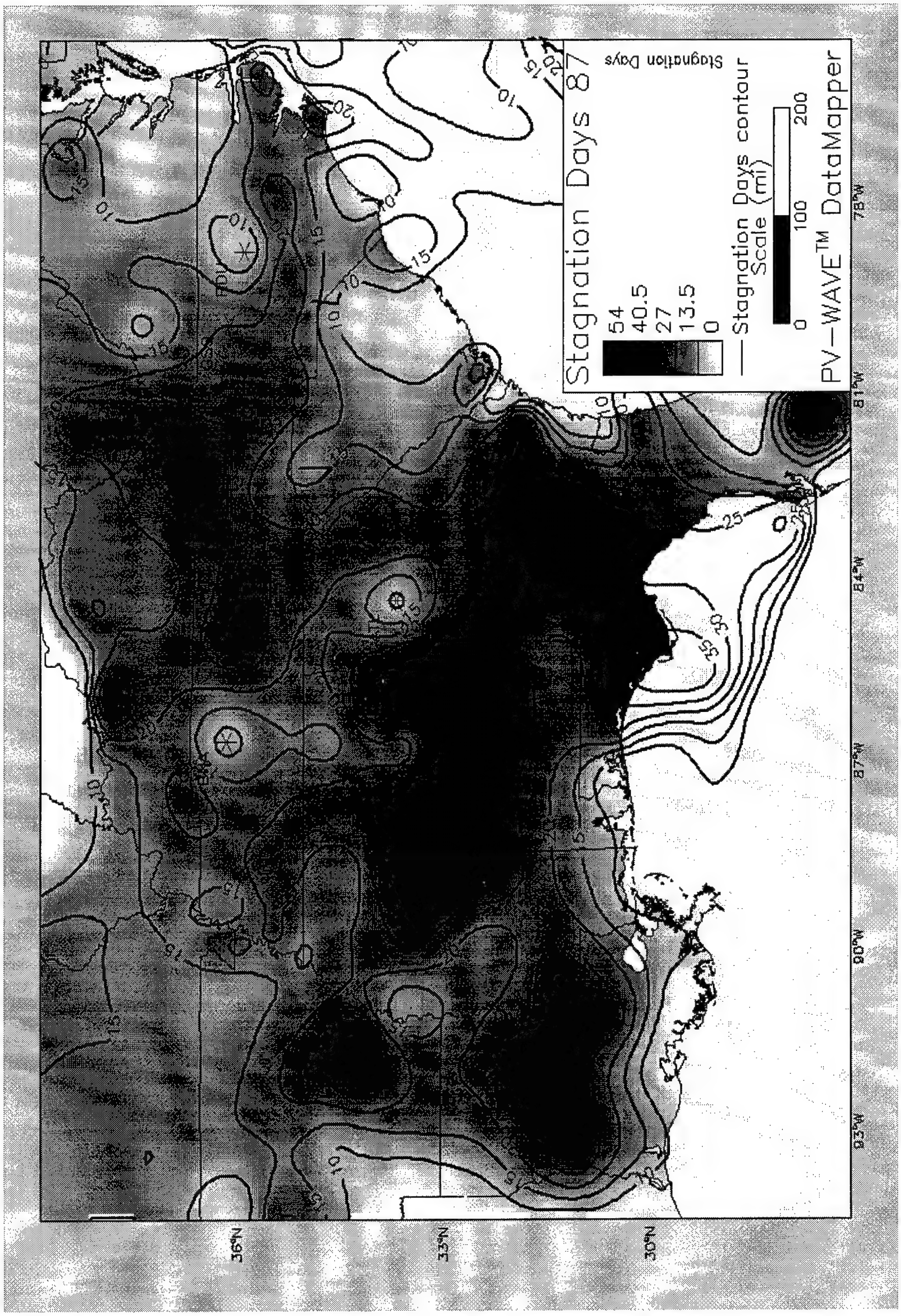
Stagnation Days 82
54
40.5
27
13.5
0
Stagnation Days
— Stagnation Days contour
Scale (mi)
0
100
200
PV—WAVE™ DataMapper
RDU
36°N
33°N
30°N
93°W
90°W
87°W
84°W
81°W
78°W


Stagnation Days 83
54
40.5
27
13.5
0
Stagnation Days
Stagnation Days contour
Scale (mi)
0
100
200
PV—WAVE™ DataMapper
36°N
33°N
30°N
93°W
90°W
87°W
84°W
81°W
78°W


Stagnation Days 84
54
40.5
27
13.5
0
Stagnation Days contour
Scale (mi)
0
100
200
PV—WAVE™ DataMapper
Stagnation Days
RDU
GSO
36°N
33°N
30°N
93°W
90°W
87°W
84°W
81°W
78°W


Stagnation Days 85
54
40.5
27
13.5
0
Stagnation Days
Stagnation Days contour
Scale (mi)
0
100
200
PV-WAVE™ DataMapper
36°N
33°N
30°N
93°W
90°W
87°W
84°W
81°W
78°W
GSO
RDU
CLT

Stagnation Days 86
Stagnation Days
54
40.5
27
13.5
0
Stagnation Days contour
Scale (mi)
0
100
200
PV–WAVE™ DataMapper
RDU
GSO
CLT
ATL
36°N
33°N
30°N
93°W
90°W
87°W
84°W
81°W
78°W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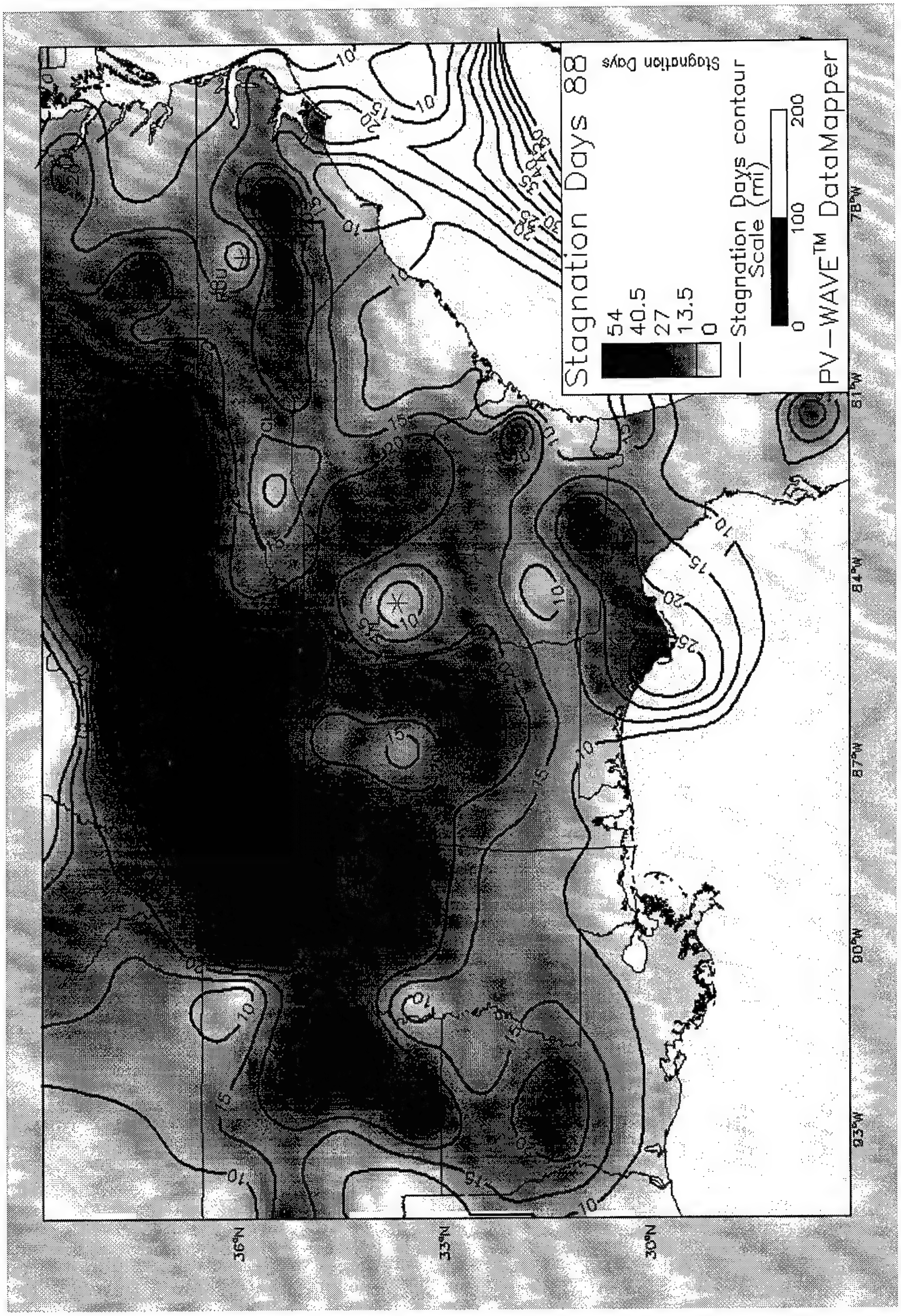
54
40.5
27
13.5
0
Stagnation Days contour
Scale (mi)
0
100
200
PV-WAVE™ DataMapper
93°W
90°W
87°W
84°W
81°W
78°W
36°N
33°N
30°N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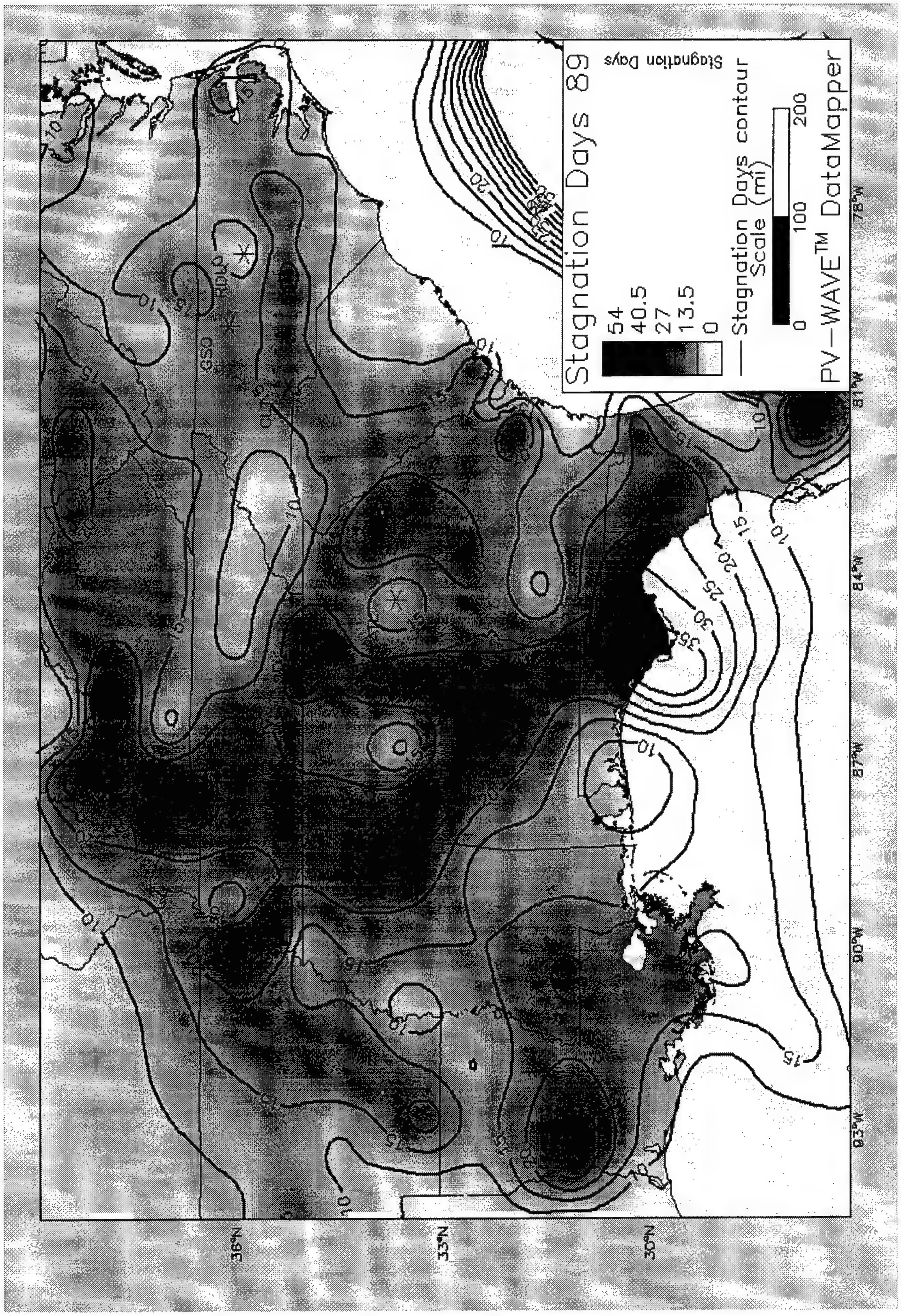
54
40.5
27
13.5
0
Stagnation Days contour
Scale (mi)
0 100 200
PV-WAVE™ DataMapper
Stagnation Days
36°N
33°N
30°N
93°W
90°W
87°W
84°W
81°W
78°W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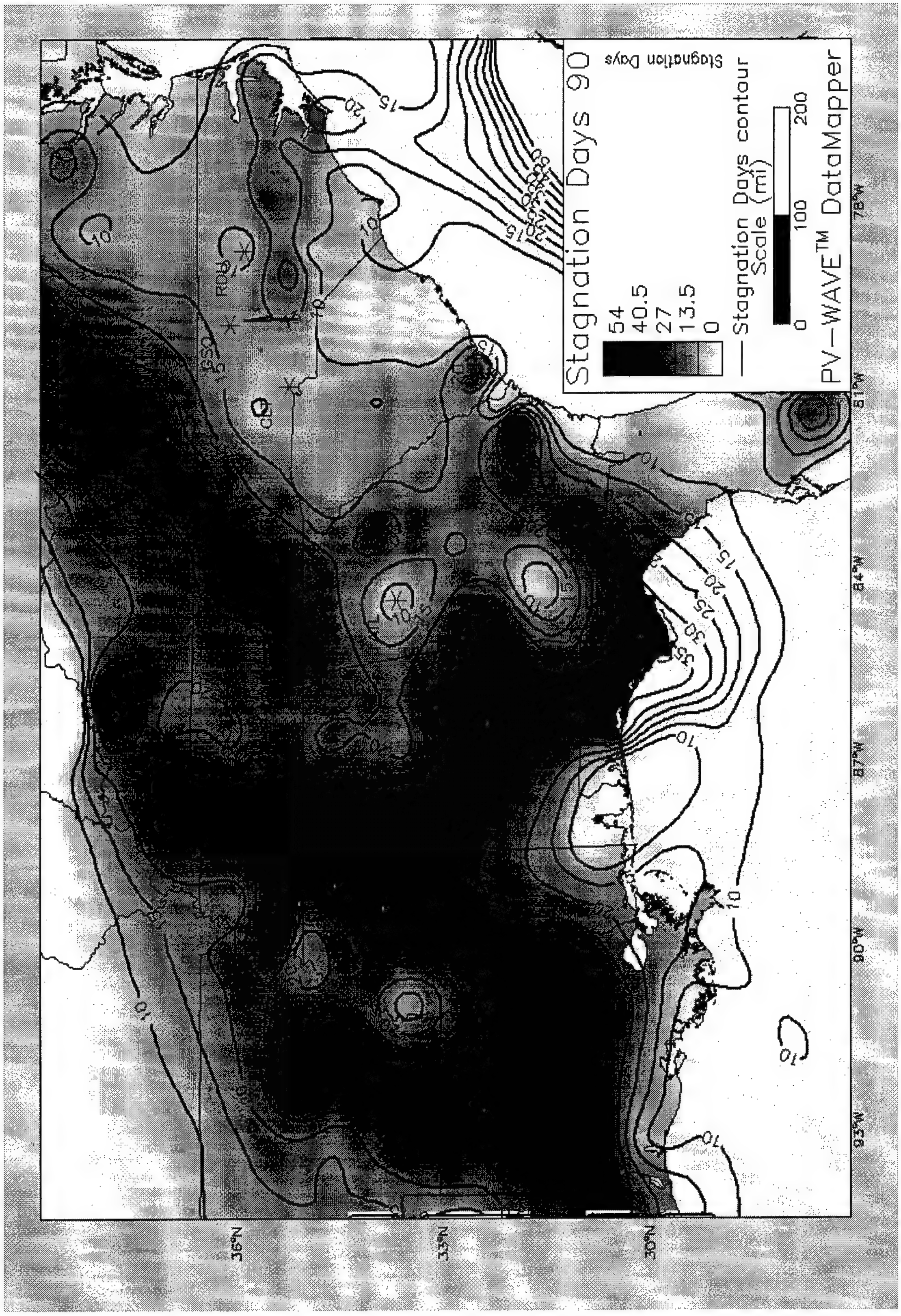
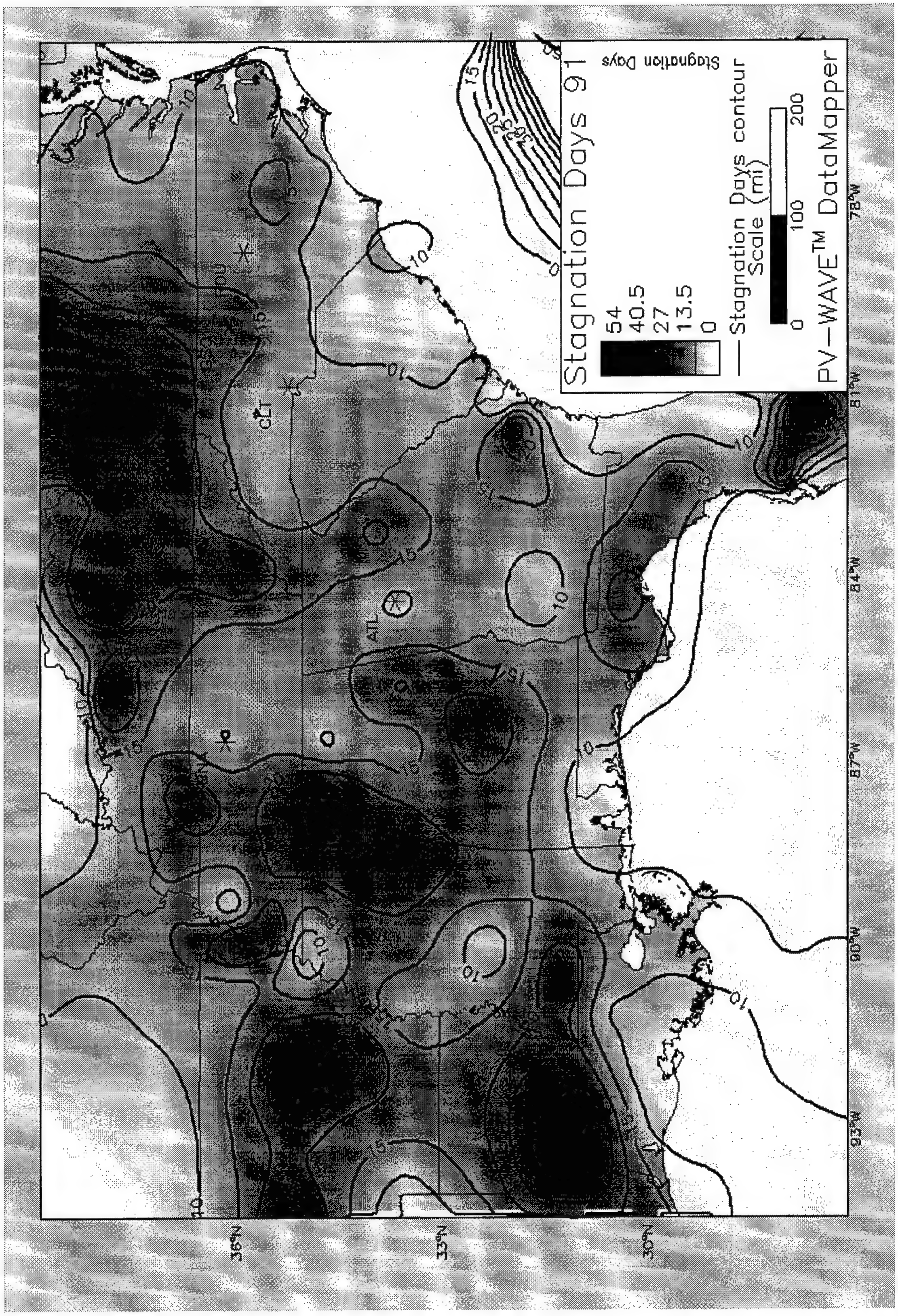
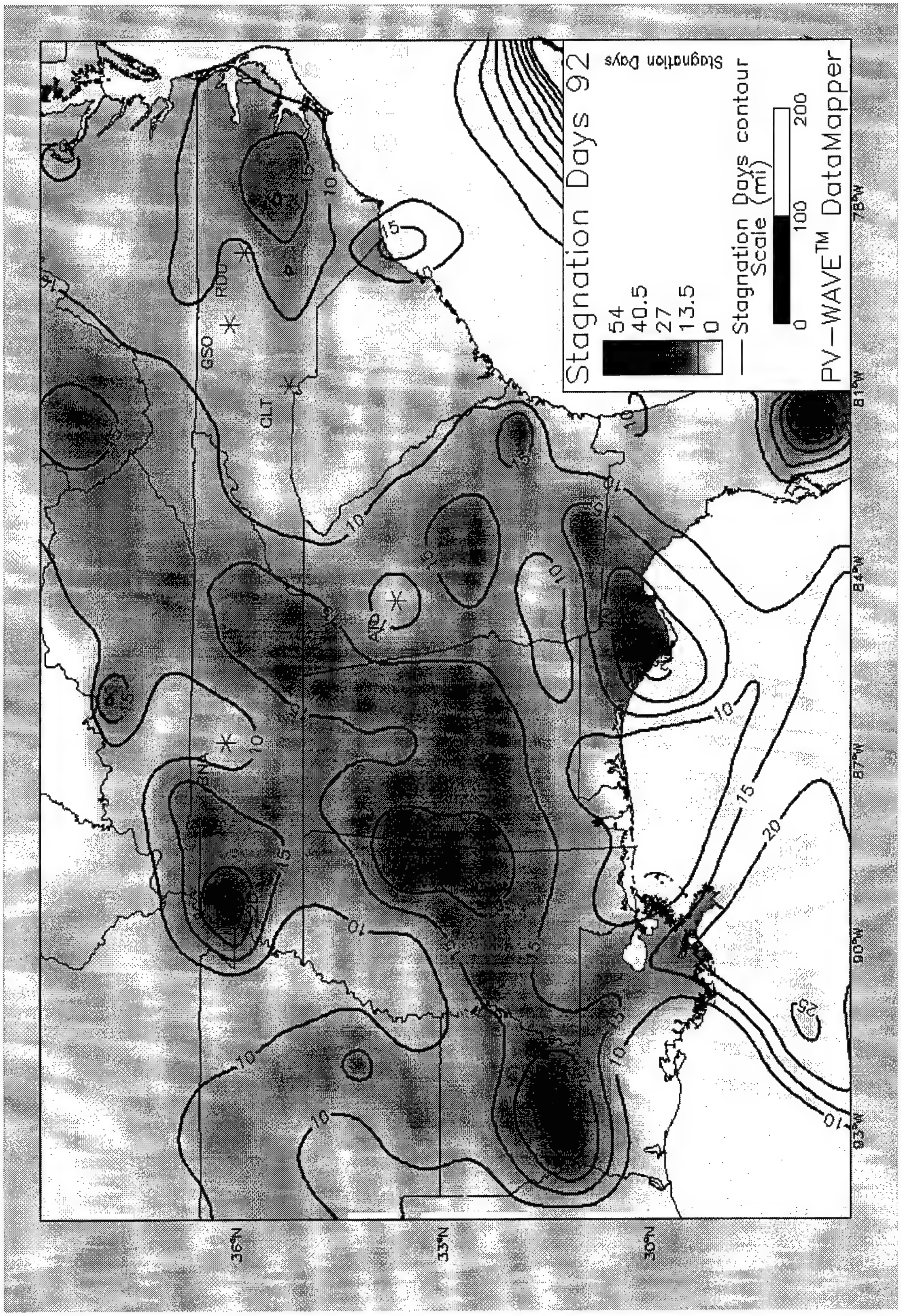
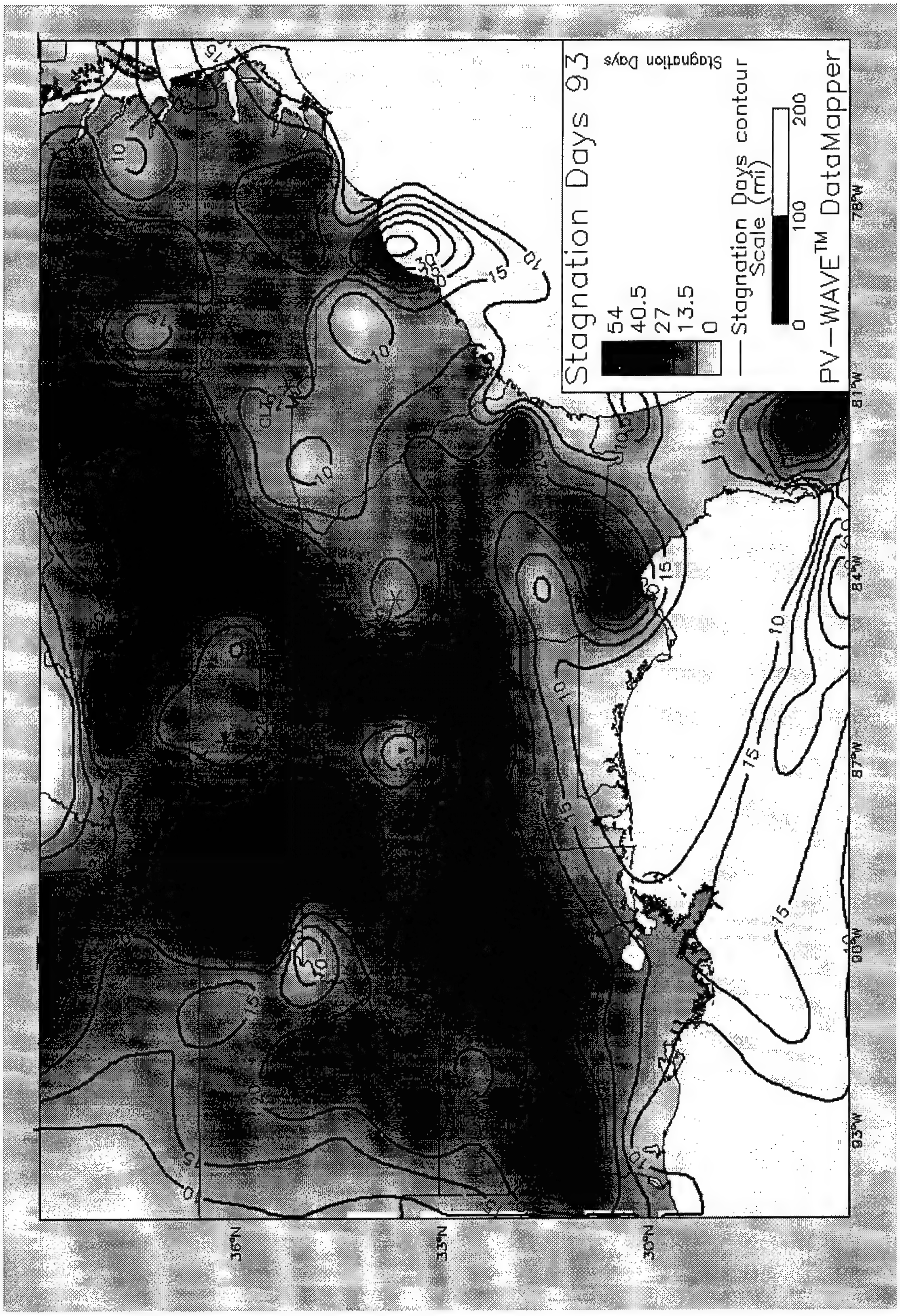
54
40.5
27
13.5
0
Stagnation Days contour
Scale (mi)
0
100
200
PV—WAVE™ DataMapper
Stagnation Days
36°N
33°N
30°N
93°W
90°W
87°W
84°W
81°W
78°W


Stagnation Days 90
54
40.5
27
13.5
0
Stagnation Days contour
Scale (mi)
0
100
200
PV—WAVE™ DataMapper
36°N
33°N
30°N
93°W
90°W
87°W
84°W
81°W
78°W
GSO
RDU

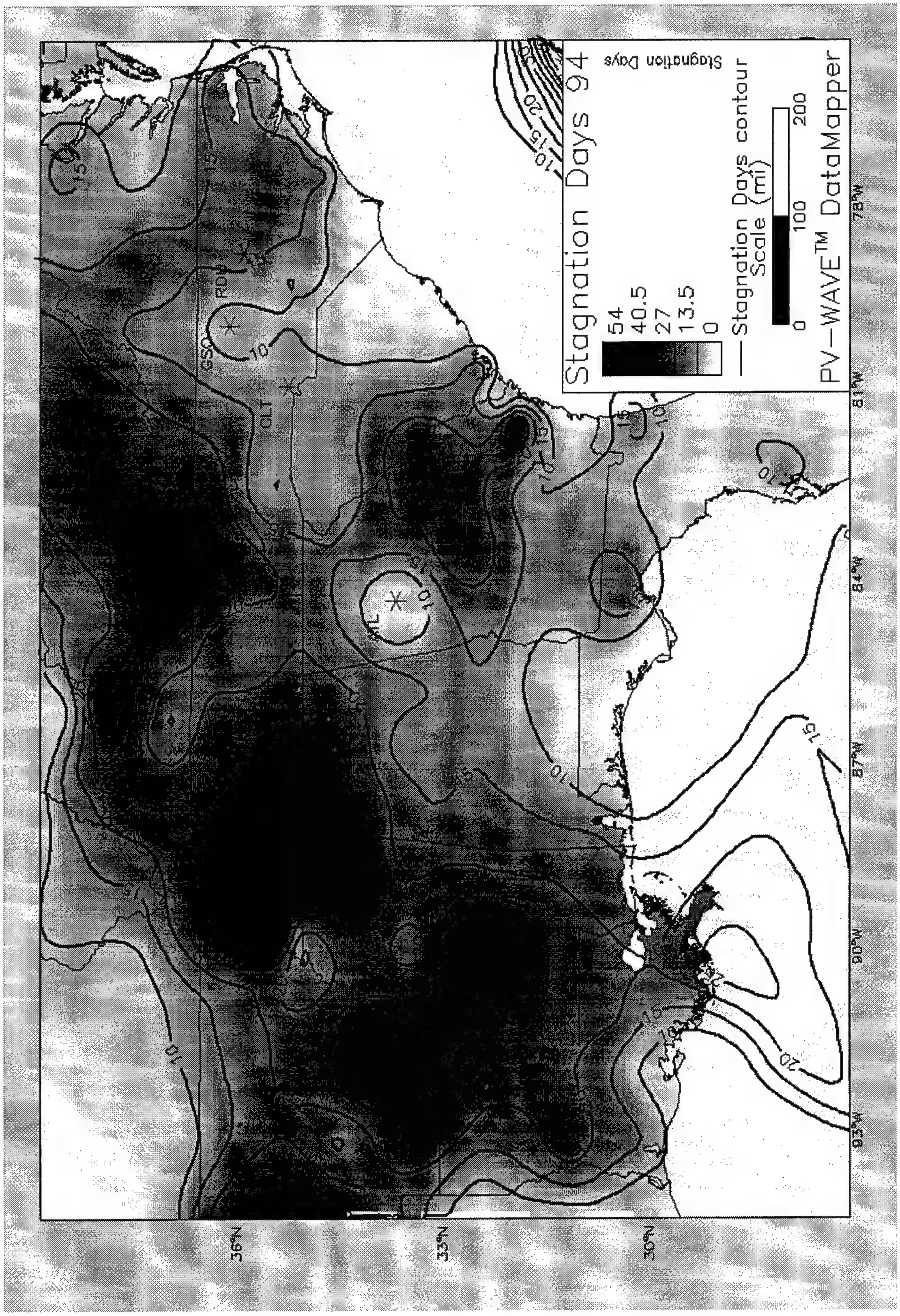


Stagnation Days 91
54
40.5
27
13.5
0
Stagnation Days contour
Scale (mi)
0
100
200
PV-WAVE™ DataMapper
Stagnation Days
ATL
CLT
36°N
33°N
30°N
93°W
90°W
87°W
84°W
81°W
78°W


Stagnation Days 92
54
40.5
27
13.5
0
Stagnation Days contour
Scale (mi)
0
100
200
PV—WAVE™ DataMapper
GSO
RDU
CLT
BNA
ATL
36°N
33°N
30°N
93°W
90°W
87°W
84°W
81°W
78°W



Stagnation Days 93
54
40.5
27
13.5
0
Stagnation Days contour
Scale (mi)
0
100
200
PV-WAVE™ DataMapper
36°N
33°N
30°N
93°W
90°W
87°W
84°W
81°W
78°W


Stagnation Days 94
54
40.5
27
13.5
0
Stagnation Days
Stagnation Days contour
Scale (mi)
0
100
200
PV—WAVE™ DataMapper
36°N
33°N
30°N
93°W
90°W
87°W
84°W
81°W
78°W
GSO
RDU
CLT
ATL

APPENDIX 2

Monthly Data

APPENDIX 2. Reduced monthly data files used in the analysis.

The following pages contain tables with the monthly averaged data as used in the data analysis. Reproduction of the original raw hourly data is not feasible since it would require several hundred pages of text. Each row in the tables represents one month's worth of data for the entire region (all nine sites), based on daily-averaged data as described in Sections 2.3 and 2.4, as used for the entire analysis except for Section 3.2.2. Reproduction of the data used for Section 3.2.2. (individual site intercomparison analysis) would require over 100 pages of data if presented in the format used here. The tables are broken down by parameter, then by month, and finally by year. Weighted averages of the monthly averages presented in these tables may be computed to obtain the seasonal averages analyzed in section 3.2.

The following is a guide to interpreting the column headings.

Heading	Represents
month	month for which the data is analyzed
year	year for which data is analyzed; rows labeled 80-94 represent climatologically averaged data
n	number of site days of data available for analysis, totaled across ALL SITES
average	average for the given parameter in the month and year as stated for that row
std. dev.	standard deviation for the given parameter in the month and year as stated for that row
maximum	maximum value for the given parameter in the month and year as stated for that row
minimum	minimum value for the given parameter in the month and year as stated for that row
deviation	deviation from climatological average for the given parameter in the month and year as stated for that row

variable=maximum o3 concentration

month	year	n	average	std. dev.	maximum	minimum	deviation
april	80	120	0.052603	0.024297	0.111553	0.007	-0.003866
april	81	219	0.052164	0.014473	0.102893	0.018	-0.004305
april	82	227	0.050011	0.014683	0.115118	0.012	-0.006458
april	83	220	0.05018	0.015289	0.095	0.01	-0.006289
april	84	225	0.051425	0.014838	0.101	0.01	-0.005044
april	85	259	0.058648	0.014204	0.097	0.02	0.002179
april	86	250	0.065187	0.020192	0.142115	0.010697	0.008718
april	87	235	0.059187	0.015824	0.105	0.01	0.002718
april	88	244	0.061303	0.012962	0.097	0.015	0.004834
april	89	243	0.062103	0.016304	0.1	0.027	0.005634
april	90	245	0.059106	0.013288	0.105	0.028	0.002637
april	91	233	0.052876	0.014327	0.096	0.02	-0.003593
april	92	262	0.053332	0.016105	0.097	0.015	-0.003137
april	93	230	0.056396	0.011909	0.1	0.021	-7.3E-05
april	94	223	0.058659	0.014102	0.106	0.02	0.00219
april	80-94	3435	0.056469	0.016108	0.142115	0.007	0
may	80	144	0.059146	0.024205	0.129381	0.005094	-0.004468
may	81	212	0.059609	0.020438	0.110024	0.006	-0.004005
may	82	248	0.068688	0.020259	0.120212	0.014772	0.005074
may	83	239	0.056605	0.017218	0.13	0.024959	-0.007009
may	84	250	0.059892	0.017576	0.116	0.005	-0.003722
may	85	252	0.062598	0.018049	0.130399	0.022	-0.001016
may	86	253	0.065376	0.018026	0.107	0.005	0.001762
may	87	268	0.064287	0.017157	0.104	0.005	0.000673
may	88	268	0.078041	0.017731	0.137	0.03	0.014427
may	89	262	0.065756	0.014134	0.109	0.029	0.002142
may	90	250	0.06046	0.015591	0.102	0.01	-0.003154
may	91	246	0.056419	0.019971	0.116	0.015	-0.007195
may	92	244	0.062832	0.021236	0.124	0.019	-0.000782
may	93	255	0.065153	0.015337	0.128	0.025	0.001539
may	94	227	0.065366	0.017122	0.124	0.025	0.001752
may	80-94	3618	0.063614	0.018926	0.137	0.005	0
june	80	184	0.067159	0.019942	0.118174	0.014	-0.003448
june	81	246	0.066278	0.023705	0.154849	0.005094	-0.004329
june	82	256	0.062732	0.019619	0.165037	0.024959	-0.007875
june	83	241	0.062474	0.020755	0.135	0.019	-0.008133
june	84	243	0.076497	0.020699	0.147209	0.013	0.00589
june	85	260	0.069929	0.019422	0.144662	0.027506	-0.000678
june	86	254	0.078529	0.024538	0.165037	0.015	0.007922
june	87	262	0.072252	0.022708	0.15	0.025	0.001645
june	88	253	0.095854	0.025662	0.169	0.02	0.025247
june	89	263	0.062589	0.021158	0.137	0.021	-0.008018
june	90	260	0.074658	0.021709	0.148	0.025	0.004051
june	91	263	0.06849	0.018038	0.124	0.005	-0.002117
june	92	252	0.061246	0.016597	0.109	0.01	-0.009361
june	93	267	0.071281	0.01838	0.129	0.02	0.000674
june	94	232	0.067944	0.020412	0.127	0.025	-0.002663
june	80-94	3736	0.070607	0.022657	0.169	0.005	0
july	80	209	0.076795	0.026286	0.15383	0.01	0.004699
july	81	240	0.073173	0.02663	0.144662	0.005094	0.001077
july	82	274	0.062414	0.020298	0.154849	0.009678	-0.009682
july	83	273	0.084345	0.026676	0.19458	0.012734	0.012249
july	84	258	0.060889	0.023426	0.154849	0.02	-0.011207
july	85	265	0.070413	0.023943	0.148	0.024959	-0.001683
july	86	255	0.084897	0.025703	0.163509	0.021	0.012801
july	87	268	0.077049	0.027665	0.201	0.02	0.004953

july	88	274	0.081347	0.028425	0.186	0.017	0.009251
july	89	272	0.063934	0.021772	0.14	0.015	-0.008162
july	90	277	0.07226	0.021837	0.152	0.018	0.000164
july	91	270	0.070522	0.02212	0.133	0.02	-0.001574
july	92	259	0.063907	0.020608	0.123	0.02	-0.008189
july	93	277	0.083365	0.02321	0.174	0.02	0.011269
july	94	242	0.055058	0.018725	0.123	0.015	-0.017038
july	80-94	3913	0.072096	0.025566	0.201	0.005094	0
aug	80	269	0.078151	0.025519	0.149756	0.02	0.008975
aug	81	254	0.061565	0.019423	0.119703	0.02	-0.007611
aug	82	257	0.063513	0.019519	0.124796	0.017828	-0.005663
aug	83	245	0.085408	0.025557	0.154849	0.005094	0.016232
aug	84	269	0.062284	0.022293	0.147209	0.010187	-0.006892
aug	85	267	0.057916	0.019793	0.122249	0.020375	-0.01126
aug	86	261	0.063639	0.024188	0.142	0.01	-0.005537
aug	87	269	0.081059	0.025359	0.169	0.025	0.011883
aug	88	268	0.075504	0.027084	0.159	0.026	0.006328
aug	89	269	0.061654	0.01989	0.162	0.015	-0.007522
aug	90	278	0.079888	0.021685	0.181	0.036	0.010712
aug	91	266	0.065489	0.020899	0.126	0.024	-0.003687
aug	92	265	0.062038	0.019427	0.132	0.023	-0.007138
aug	93	276	0.075594	0.020394	0.142	0.03	0.006418
aug	94	241	0.063187	0.02233	0.122	0.019	-0.005989
aug	80-94	3954	0.069176	0.023948	0.181	0.005094	0
sept	80	244	0.061059	0.02508	0.149756	0.005	0.002468
sept	81	251	0.064518	0.024487	0.156	0.011	0.005927
sept	82	257	0.057335	0.018926	0.104931	0.01	-0.001256
sept	83	247	0.060947	0.021898	0.136	0.014772	0.002356
sept	84	245	0.057338	0.023181	0.132437	0.010187	-0.001253
sept	85	245	0.055746	0.019653	0.111	0.005094	-0.002845
sept	86	249	0.05282	0.018823	0.11359	0.005	-0.005771
sept	87	227	0.062718	0.018058	0.132	0.016	0.004127
sept	88	241	0.058651	0.020423	0.126	0.018	6E-05
sept	89	225	0.052756	0.018086	0.096	0.01	-0.005835
sept	90	256	0.069102	0.020275	0.146	0.025	0.010511
sept	91	264	0.062659	0.021084	0.131	0.005	0.004068
sept	92	254	0.048366	0.016192	0.096	0.01	-0.010225
sept	93	260	0.057292	0.017091	0.129	0.011	-0.001299
sept	94	229	0.056956	0.015902	0.103	0.02	-0.001635
sept	80-94	3694	0.058591	0.02074	0.156	0.005	0
oct	80	228	0.039186	0.018048	0.098309	0.004	-0.006753
oct	81	215	0.045102	0.016673	0.104931	0.004	-0.000837
oct	82	193	0.042984	0.020231	0.111	0.01	-0.002955
oct	83	234	0.046121	0.020712	0.117	0.003	0.000182
oct	84	257	0.046382	0.021015	0.111	0.003	0.000443
oct	85	190	0.043028	0.016679	0.107478	0.005	-0.002911
oct	86	252	0.046663	0.014801	0.08	0.009	0.000724
oct	87	264	0.051621	0.01722	0.097	0.01	0.005682
oct	88	259	0.043471	0.012313	0.078	0.005	-0.002468
oct	89	253	0.052909	0.019526	0.1	0.004	0.00697
oct	90	252	0.045413	0.015244	0.088	0.01	-0.000526
oct	91	275	0.046789	0.014824	0.098	0.005	0.00085
oct	92	262	0.048336	0.012599	0.082	0.005	0.002397
oct	93	248	0.045101	0.01555	0.092	0.01	-0.000838
oct	94	213	0.04293	0.013079	0.08	0.01	-0.003009
oct	80-94	3595	0.045939	0.017028	0.117	0.003	0

variable=average o3 concentration

month	year	n	average	std. dev.	maximum	minimum	deviation
april	80	120	0.046827	0.023625	0.103742	0	-0.003881
april	81	219	0.046483	0.013877	0.083877	0.011833	-0.004225
april	82	227	0.043423	0.014658	0.075048	0	-0.007285
april	83	220	0.044313	0.01644	0.085	0	-0.006395
april	84	225	0.045197	0.014658	0.09	0	-0.005511
april	85	259	0.05365	0.01345	0.089833	0.011667	0.002942
april	86	250	0.058626	0.019151	0.113081	0	0.007918
april	87	235	0.053394	0.015284	0.095833	0.002	0.002686
april	88	244	0.055984	0.012901	0.0876	0.010833	0.005276
april	89	243	0.056321	0.015928	0.091833	0	0.005613
april	90	245	0.053327	0.012773	0.093833	0.0155	0.002619
april	91	233	0.04677	0.014699	0.08625	0	-0.003938
april	92	262	0.048379	0.015588	0.087	0.010833	-0.002329
april	93	230	0.050915	0.012982	0.081333	0	0.000207
april	94	223	0.052982	0.014218	0.0984	0.015667	0.002274
april	80-94	3435	0.050708	0.015927	0.113081	0	0
may	80	144	0.050956	0.023339	0.112062	0	-0.005698
may	81	212	0.052985	0.019828	0.096186	0	-0.003669
may	82	248	0.059328	0.02093	0.112571	0	0.002674
may	83	239	0.050112	0.016759	0.102833	0	-0.006542
may	84	250	0.053063	0.017509	0.102833	0.004	-0.003591
may	85	252	0.055962	0.016616	0.095168	0.02	-0.000692
may	86	253	0.05858	0.017905	0.096167	0	0.001926
may	87	268	0.056682	0.016871	0.0955	0	2.8E-05
may	88	268	0.070403	0.018175	0.126167	0	0.013749
may	89	262	0.059985	0.012718	0.0946	0.022167	0.003331
may	90	250	0.053523	0.015934	0.0894	0	-0.003131
may	91	246	0.04992	0.018452	0.10425	0.009333	-0.006734
may	92	244	0.055868	0.020579	0.1055	0	-0.000786
may	93	255	0.058596	0.014575	0.106667	0.02	0.001942
may	94	227	0.059536	0.016367	0.1096	0.0215	0.002882
may	80-94	3618	0.056654	0.018416	0.126167	0	0
june	80	184	0.058996	0.020253	0.108836	0	-0.002645
june	81	246	0.056646	0.020972	0.133201	0	-0.004995
june	82	256	0.053611	0.016983	0.112667	0	-0.00803
june	83	241	0.054281	0.02109	0.1185	0	-0.00736
june	84	243	0.065243	0.018733	0.120667	0	0.003602
june	85	260	0.061322	0.017129	0.115288	0.020333	-0.000319
june	86	254	0.068937	0.021477	0.131333	0.008333	0.007296
june	87	262	0.062972	0.020699	0.1282	0.014167	0.001331
june	88	253	0.084511	0.025054	0.1446	0	0.02287
june	89	263	0.054549	0.019238	0.1215	0.0185	-0.007092
june	90	260	0.066055	0.019707	0.1285	0	0.004414
june	91	263	0.060366	0.016652	0.113167	0.003	-0.001275
june	92	252	0.054887	0.015995	0.099	0.005	-0.006754
june	93	267	0.062354	0.016375	0.111333	0.017333	0.000713
june	94	232	0.058752	0.018704	0.110667	0.015167	-0.002889
june	80-94	3736	0.061641	0.020801	0.1446	0	0
july	80	209	0.066111	0.023848	0.137191	0	0.003866
july	81	240	0.060943	0.02427	0.123098	0	-0.001302
july	82	274	0.052282	0.017569	0.149756	0	-0.009963
july	83	273	0.072702	0.024225	0.166565	0	0.010457
july	84	258	0.051751	0.019473	0.127343	0.015	-0.010494
july	85	265	0.061271	0.021834	0.127167	0	-0.000974
july	86	255	0.073841	0.022498	0.149076	0	0.011596
july	87	268	0.067267	0.024427	0.150667	0	0.005022

july	88	274	0.071187	0.026143	0.156	0	0.008942
july	89	272	0.055608	0.019645	0.117833	0.005833	-0.006637
july	90	277	0.06394	0.021047	0.125167	0	0.001695
july	91	270	0.061417	0.020342	0.12	0.015833	-0.000828
july	92	259	0.054972	0.018899	0.1105	0.002	-0.007273
july	93	277	0.072418	0.021103	0.155833	0	0.010173
july	94	242	0.046614	0.017173	0.111	0.007667	-0.015631
july	80-94	3913	0.062245	0.023123	0.166565	0	0
aug	80	269	0.066966	0.02213	0.116052	0.012833	0.007163
aug	81	254	0.052829	0.017642	0.101195	0	-0.006974
aug	82	257	0.054208	0.017308	0.112673	0	-0.005595
aug	83	245	0.073795	0.024429	0.14237	0	0.013992
aug	84	269	0.053486	0.02029	0.12337	0	-0.006317
aug	85	267	0.05029	0.017832	0.106204	0.010833	-0.009513
aug	86	261	0.055021	0.021845	0.120212	0	-0.004782
aug	87	269	0.069801	0.021965	0.1445	0.014167	0.009998
aug	88	268	0.065015	0.023876	0.142667	0.021667	0.005212
aug	89	269	0.053632	0.017029	0.113333	0.003833	-0.006171
aug	90	278	0.06974	0.019288	0.151167	0	0.009937
aug	91	266	0.057065	0.019713	0.113833	0	-0.002738
aug	92	265	0.053742	0.017002	0.110667	0.0134	-0.006061
aug	93	276	0.066221	0.018744	0.113	0	0.006418
aug	94	241	0.054479	0.020119	0.110833	0.0115	-0.005324
aug	80-94	3954	0.059803	0.021407	0.151167	0	0
sept	80	244	0.051651	0.022387	0.106798	0	0.000327
sept	81	251	0.054868	0.021304	0.118667	0	0.003544
sept	82	257	0.049265	0.017674	0.092706	0.009169	-0.002059
sept	83	247	0.053721	0.020515	0.119833	0	0.002397
sept	84	245	0.050404	0.021189	0.118684	0	-0.00092
sept	85	245	0.050055	0.018382	0.1025	0	-0.001269
sept	86	249	0.04642	0.017385	0.096271	0	-0.004904
sept	87	227	0.055678	0.016857	0.108333	0	0.004354
sept	88	241	0.051516	0.018747	0.1055	0.009	0.000192
sept	89	225	0.046155	0.017147	0.087667	0	-0.005169
sept	90	256	0.061569	0.018752	0.14125	0	0.010245
sept	91	264	0.054922	0.019224	0.1046	0.002	0.003598
sept	92	254	0.042074	0.015488	0.0865	0.006667	-0.00925
sept	93	260	0.050298	0.015824	0.1125	0.008667	-0.001026
sept	94	229	0.050873	0.015308	0.09	0.014667	-0.000451
sept	80-94	3694	0.051324	0.019055	0.14125	0	0
oct	80	228	0.033295	0.016245	0.085167	0.004	-0.006669
oct	81	215	0.038522	0.014994	0.084131	0	-0.001442
oct	82	193	0.03688	0.018499	0.085667	0.004833	-0.003084
oct	83	234	0.038958	0.019618	0.102167	0	-0.001006
oct	84	257	0.039899	0.01926	0.094828	0	-6.5E-05
oct	85	190	0.037038	0.015925	0.088716	0	-0.002926
oct	86	252	0.040823	0.014558	0.071167	0	0.000859
oct	87	264	0.04608	0.016141	0.083	0.004667	0.006116
oct	88	259	0.038161	0.01252	0.073333	0.0035	-0.001803
oct	89	253	0.046675	0.017869	0.090333	0.003167	0.006711
oct	90	252	0.039545	0.014447	0.08	0	-0.000419
oct	91	275	0.041709	0.013652	0.079667	0.005	0.001745
oct	92	262	0.042183	0.012004	0.0725	0.005	0.002219
oct	93	248	0.039082	0.014878	0.079833	0	-0.000882
oct	94	213	0.037309	0.012924	0.077333	0.0075	-0.002655
oct	80-94	3595	0.039964	0.016004	0.102167	0	0

variable=maximum daily temperature

month	year	n	average	std. dev.	maximum	minimum	deviation
april	80	120	73.125	7.7963	94	56	0.7978
april	81	219	76.2831	6.794	90	60	3.9559
april	82	227	67.859	7.8986	83	46	-4.4682
april	83	220	65.5182	8.8263	84	41	-6.809
april	84	225	68.1111	8.5707	87	44	-4.2161
april	85	259	74.8456	9.3365	90	48	2.5184
april	86	250	76.232	8.6434	92	53	3.9048
april	87	235	70.7191	10.7257	89	43	-1.6081
april	88	244	73.2705	6.3181	89	52	0.9433
april	89	243	71.5144	11.9767	91	43	-0.8128
april	90	245	72.8816	9.2448	92	51	0.5544
april	91	233	74.7983	6.4426	85	57	2.4711
april	92	262	72.0649	10.2205	86	45	-0.2623
april	93	230	70.5174	7.0906	84	46	-1.8098
april	94	223	76.7623	7.2821	88	54	4.4351
april	80-94	3435	72.3272	9.2481	94	41	0
may	80	144	79.5069	5.6432	90	65	0.1423
may	81	212	78.1274	6.2133	91	62	-1.2372
may	82	248	82.5363	4.4593	92	72	3.1717
may	83	239	77.2469	4.5662	87	62	-2.1177
may	84	250	77.044	5.8921	87	63	-2.3206
may	85	252	79.373	5.7	91	58	0.0084
may	86	253	80.1383	6.3858	91	57	0.7737
may	87	268	81.9739	5.2939	90	65	2.6093
may	88	268	79.9216	6.0532	93	64	0.557
may	89	262	77.1565	8.1218	93	58	-2.2081
may	90	250	78.996	5.8099	90	61	-0.3686
may	91	246	82.6423	5.4677	94	59	3.2777
may	92	244	77.418	8.2635	89	51	-1.9466
may	93	255	79.8235	5.5355	88	66	0.4589
may	94	227	78.1189	6.2584	89	62	-1.2457
may	80-94	3618	79.3646	6.3462	94	51	0
june	80	184	85.4565	5.8905	97	66	-0.9153
june	81	246	88.3862	4.6984	100	76	2.0144
june	82	256	83.8203	3.7499	92	75	-2.5515
june	83	241	83.8299	4.3732	93	69	-2.5419
june	84	243	87.2634	4.3585	97	75	0.8916
june	85	260	85.9038	5.6509	97	71	-0.468
june	86	254	88.9685	4.2192	98	76	2.5967
june	87	262	86.6794	3.1508	93	77	0.3076
june	88	253	88.4348	6.8592	101	70	2.063
june	89	263	85.1369	4.9196	95	71	-1.2349
june	90	260	87.7115	4.7547	95	74	1.3397
june	91	263	86.2205	4.8201	94	70	-0.1513
june	92	252	81.9683	5.5047	92	67	-4.4035
june	93	267	87.8839	4.8245	97	72	1.5121
june	94	232	87.681	4.2018	95	69	1.3092
june	80-94	3736	86.3718	5.2289	101	66	0
july	80	209	90.7321	4.9161	105	80	1.2831
july	81	240	88.8583	5.8371	98	72	-0.5907
july	82	274	86.8358	3.4702	93	76	-2.6132
july	83	273	91.0476	4.6968	101	78	1.5986
july	84	258	84.2791	5.1785	95	68	-5.1699
july	85	265	87.1396	5.3788	98	68	-2.3094
july	86	255	94.0392	4.2248	102	82	4.5902
july	87	268	90.9515	4.1608	100	81	1.5025

july	88	274	89.6825	5.4609	103	73	0.2335
july	89	272	87.1801	4.2782	96	72	-2.2689
july	90	277	89.8917	4.9988	102	77	0.4427
july	91	270	90.1444	4.7967	100	70	0.6954
july	92	259	89.5985	3.5439	97	82	0.1495
july	93	277	94.4404	3.5693	102	84	4.9914
july	94	242	86.7521	3.0098	92	77	-2.6969
july	80-94	3913	89.449	5.2742	105	68	0
aug	80	269	91.7212	4.4722	100	76	4.2609
aug	81	254	84.2244	4.9934	95	69	-3.2359
aug	82	257	84.9222	3.2944	92	74	-2.5381
aug	83	245	91.8	5.2974	103	77	4.3397
aug	84	269	85.1822	3.0285	91	77	-2.2781
aug	85	267	84.6479	4.5903	96	72	-2.8124
aug	86	261	85.7088	6.0478	96	67	-1.7515
aug	87	269	90.8625	4.7126	104	76	3.4022
aug	88	268	90.5597	4.9431	104	76	3.0994
aug	89	269	86.487	4.9116	94	72	-0.9733
aug	90	278	89.2086	4.7713	102	72	1.7483
aug	91	266	86.9023	4.591	96	75	-0.558
aug	92	265	83.6453	5.1252	95	69	-3.815
aug	93	276	89.7862	4.3503	97	76	2.3259
aug	94	241	85.9378	3.519	94	76	-1.5225
aug	80-94	3954	87.4603	5.4105	104	67	0
sept	80	244	85.8893	8.1154	98	59	3.9827
sept	81	251	80.6335	5.2055	89	65	-1.2731
sept	82	257	79.1089	5.8633	90	67	-2.7977
sept	83	247	81.8502	9.1317	98	64	-0.0564
sept	84	245	80.3347	8.1649	92	52	-1.5719
sept	85	245	81.3592	6.6771	93	65	-0.5474
sept	86	249	82.4739	5.8324	93	67	0.5673
sept	87	227	82.6432	4.0995	92	73	0.7366
sept	88	241	80.9295	5.5931	92	66	-0.9771
sept	89	225	81.1422	7.6513	93	55	-0.7644
sept	90	256	84.1211	6.7798	101	67	2.2145
sept	91	264	82.9811	7.6682	96	66	1.0745
sept	92	254	80.437	6.2258	89	63	-1.4696
sept	93	260	84.2538	6.4775	96	62	2.3472
sept	94	229	80.2096	5.2113	91	67	-1.697
sept	80-94	3694	81.9066	6.9402	101	52	0
oct	80	228	70.7632	8.231	89	48	-1.476
oct	81	215	70.2233	8.2074	88	46	-2.0159
oct	82	193	71.6788	7.8283	86	50	-0.5604
oct	83	234	72.2308	7.5784	87	51	-0.0084
oct	84	257	77.0272	5.6398	85	57	4.788
oct	85	190	75.1579	6.9264	88	58	2.9187
oct	86	252	73.1389	8.3838	93	59	0.8997
oct	87	264	69.4811	6.5112	82	52	-2.7581
oct	88	259	66.6564	6.5493	82	50	-5.5828
oct	89	253	73.9407	7.8715	85	44	1.7015
oct	90	252	74.0278	7.7964	87	55	1.7886
oct	91	275	74.2945	6.2149	85	59	2.0553
oct	92	262	70.687	6.2005	85	53	-1.5522
oct	93	248	72.75	8.655	86	40	0.5108
oct	94	213	71.6573	6.0188	84	54	-0.5819
oct	80-94	3595	72.2392	7.6871	93	40	0

variable=average daily temperature

month	year	n	average	std. dev.	maximum	minimum	deviation
april	80	120	56.3667	7.1113	71	39	0.1845
april	81	219	60.1826	6.7873	71	41	4.0004
april	82	227	53.2819	8.3119	68	30	-2.9003
april	83	220	50.4727	8.5978	67	32	-5.7095
april	84	225	53.5244	7.3211	69	39	-2.6578
april	85	259	58.0154	8.7568	72	32	1.8332
april	86	250	58.14	8.2861	71	38	1.9578
april	87	235	54.0085	9.7178	73	31	-2.1737
april	88	244	55.9713	7.1269	70	39	-0.2109
april	89	243	55.8477	10.5155	75	34	-0.3345
april	90	245	56.0694	9.1857	73	36	-0.1128
april	91	233	59.8541	6.4738	72	44	3.6719
april	92	262	56.1603	9.8037	70	32	-0.0219
april	93	230	54.3348	7.5383	69	37	-1.8474
april	94	223	60.2018	8.5059	74	37	4.0196
april	80-94	3435	56.1822	8.8195	75	30	0
may	80	144	64.4167	6.2852	76	46	-0.0742
may	81	212	61.7406	6.8327	77	46	-2.7503
may	82	248	66.6492	5.1803	80	50	2.1583
may	83	239	62.2929	5.866	72	47	-2.198
may	84	250	61.916	6.8081	75	47	-2.5749
may	85	252	64.6349	5.3568	79	48	0.144
may	86	253	65.1462	6.2601	75	47	0.6553
may	87	268	67.4888	5.6902	76	50	2.9979
may	88	268	63.4813	5.2342	75	51	-1.0096
may	89	262	62.9198	7.8602	80	41	-1.5711
may	90	250	64.952	6.3598	76	47	0.4611
may	91	246	69.6829	5.5037	79	53	5.192
may	92	244	62.5533	6.783	74	46	-1.9376
may	93	255	65.7216	5.2163	74	52	1.2307
may	94	227	63.0396	6.5421	75	46	-1.4513
may	80-94	3618	64.4909	6.52	80	41	0
june	80	184	70.7446	5.4917	81	58	-1.7447
june	81	246	74.9431	4.2084	83	63	2.4538
june	82	256	70.7578	3.1592	78	61	-1.7315
june	83	241	70.0083	4.5971	79	55	-2.481
june	84	243	72.4033	4.3048	80	53	-0.086
june	85	260	71.7692	5.1884	84	56	-0.7201
june	86	254	74.6732	3.6181	81	65	2.1839
june	87	262	73.0878	2.8237	81	63	0.5985
june	88	253	71.8182	6.8044	85	52	-0.6711
june	89	263	72.8137	3.8778	81	63	0.3244
june	90	260	73.3962	4.5186	81	58	0.9069
june	91	263	73.0266	4.2717	82	61	0.5373
june	92	252	69.5873	4.7061	78	57	-2.902
june	93	267	73.4944	4.8569	82	56	1.0051
june	94	232	74.3233	3.4994	80	64	1.834
june	80-94	3736	72.4893	4.7424	85	52	0
july	80	209	76.3971	4.0915	88	66	0.4733
july	81	240	76.0583	4.5137	83	65	0.1345
july	82	274	74.7299	2.6616	80	63	-1.1939
july	83	273	75.8864	4.2346	86	62	-0.0374
july	84	258	72.3256	3.5488	81	61	-3.5982
july	85	265	73.6528	3.5993	83	63	-2.271
july	86	255	78.7137	3.8963	88	68	2.7899
july	87	268	76.7612	3.2179	83	68	0.8374

july	88	274	75.573	4.4578	86	61	-0.3508
july	89	272	74.8382	3.0656	83	67	-1.0856
july	90	277	76.065	3.6766	84	65	0.1412
july	91	270	76.8741	3.3781	84	65	0.9503
july	92	259	76.5058	3.2017	84	69	0.582
july	93	277	79.4801	2.7526	85	71	3.5563
july	94	242	74.9339	2.4655	81	68	-0.9899
july	80-94	3913	75.9238	3.9542	88	61	0
aug	80	269	76.5019	3.8552	84	67	2.3282
aug	81	254	72.252	4.3128	83	59	-1.9217
aug	82	257	72.5019	3.0428	79	59	-1.6718
aug	83	245	76.4	4.245	86	62	2.2263
aug	84	269	72.7918	2.7646	78	64	-1.3819
aug	85	267	72.3783	3.6018	80	62	-1.7954
aug	86	261	72.9157	4.9939	80	53	-1.258
aug	87	269	76.5539	3.6141	83	66	2.3802
aug	88	268	76.6269	3.7028	85	63	2.4532
aug	89	269	73.684	4.3871	82	60	-0.4897
aug	90	278	75.1547	3.4234	83	66	0.981
aug	91	266	74.0451	3.2872	82	65	-0.1286
aug	92	265	71.4113	3.8819	80	59	-2.7624
aug	93	276	75.8551	3.3931	84	66	1.6814
aug	94	241	73.2988	3.2599	80	63	-0.8749
aug	80-94	3954	74.1737	4.1518	86	53	0
sept	80	244	71.959	5.6107	80	52	3.8797
sept	81	251	65.6534	6.7779	76	49	-2.4259
sept	82	257	65.9144	6.208	76	49	-2.1649
sept	83	247	66.9231	9.2647	80	46	-1.1562
sept	84	245	65.0531	6.8023	78	49	-3.0262
sept	85	245	66.2327	7.7792	78	48	-1.8466
sept	86	249	69.6225	4.3545	77	55	1.5432
sept	87	227	68.9559	4.5698	76	56	0.8766
sept	88	241	68.2365	5.1029	77	55	0.1572
sept	89	225	68.92	6.6334	78	46	0.8407
sept	90	256	69.4141	7.4671	81	50	1.3348
sept	91	264	68.6705	8.1419	82	50	0.5912
sept	92	254	68.5354	5.6124	76	49	0.4561
sept	93	260	70.1962	6.7649	81	51	2.1169
sept	94	229	66.8734	5.2051	78	54	-1.2059
sept	80-94	3694	68.0793	6.8275	82	46	0
oct	80	228	54.8991	8.0704	71	36	-1.951
oct	81	215	54.8279	7.6282	74	35	-2.0222
oct	82	193	57.0466	9.2889	73	39	0.1965
oct	83	234	57.0726	6.983	73	39	0.2225
oct	84	257	62.9027	6.3062	72	43	6.0526
oct	85	190	61.4368	6.5071	72	44	4.5867
oct	86	252	59.0079	9.3058	78	40	2.1578
oct	87	264	51.1061	6.282	69	34	-5.744
oct	88	259	52.139	7.2146	72	37	-4.7111
oct	89	253	57.1462	8.4716	73	38	0.2961
oct	90	252	58.2698	9.2162	75	39	1.4197
oct	91	275	57.8945	7.3653	71	41	1.0444
oct	92	262	55.0878	6.2841	67	35	-1.7623
oct	93	248	57.371	8.1444	71	35	0.5209
oct	94	213	57.6385	6.7318	72	39	0.7884
oct	80-94	3595	56.8501	8.2077	78	34	0

variable=average wind speed

month	year	n	average	std. dev.	maximum	minimum	deviation
april	80	120	6.4583	3.084	20	1	-0.3892
april	81	219	7.3059	2.5419	15	2	0.4584
april	82	227	7.1189	3.4907	27	1	0.2714
april	83	220	7.1136	3.28	20	1	0.2661
april	84	225	6.3733	2.7014	21	1	-0.4742
april	85	259	6.2278	2.9344	22	2	-0.6197
april	86	250	6.544	2.7725	17	1	-0.3035
april	87	235	7.0298	2.7879	18	2	0.1823
april	88	244	7.4836	3.3004	22	2	0.6361
april	89	243	6.3786	2.601	15	2	-0.4689
april	90	245	6.5184	2.9706	19	1	-0.3291
april	91	233	6.1717	2.1746	16	2	-0.6758
april	92	262	7.2977	2.693	16	2	0.4502
april	93	230	8.0304	3.5394	20	1	1.1829
april	94	223	6.5471	2.4889	17	2	-0.3004
april	80-94	3435	6.8475	2.9492	27	1	0
may	80	144	5.5764	1.9236	12	2	-0.3542
may	81	212	6.2925	2.5536	15	1	0.3619
may	82	248	4.9516	1.5395	10	2	-0.979
may	83	239	6.3975	2.7357	24	2	0.4669
may	84	250	6.276	2.2972	15	2	0.3454
may	85	252	5.7183	2.4258	14	1	-0.2123
may	86	253	5.4466	2.133	11	1	-0.484
may	87	268	5.5784	1.7324	11	2	-0.3522
may	88	268	5.6045	2.4357	15	1	-0.3261
may	89	262	6.6069	2.2915	13	2	0.6763
may	90	250	7.1	2.7452	14	1	1.1694
may	91	246	5.2967	1.9973	13	1	-0.6339
may	92	244	6.2418	2.7627	20	1	0.3112
may	93	255	5.5804	1.823	12	1	-0.3502
may	94	227	6.2687	2.2661	13	3	0.3381
may	80-94	3618	5.9306	2.3407	24	1	0
june	80	184	6.1087	2.0484	11	1	0.39
june	81	246	6.1545	2.0305	12	2	0.4358
june	82	256	5.3438	1.6182	10	2	-0.3749
june	83	241	4.9004	1.8389	11	0	-0.8183
june	84	243	5.1687	1.3937	9	2	-0.55
june	85	260	5.7577	2.154	14	1	0.039
june	86	254	5.5945	2.0863	14	1	-0.1242
june	87	262	6.0229	1.7572	11	2	0.3042
june	88	253	5.7391	1.9526	13	2	0.0204
june	89	263	5.8707	1.9454	14	2	0.152
june	90	260	6.2654	1.9319	12	2	0.5467
june	91	263	5.6996	2.4505	14	1	-0.0191
june	92	252	5.6944	1.859	14	2	-0.0243
june	93	267	5.5805	1.6532	12	2	-0.1382
june	94	232	5.9353	3.0791	23	1	0.2166
june	80-94	3736	5.7187	2.0429	23	0	0
july	80	209	5.3541	1.6696	10	1	-0.0913
july	81	240	5.5375	1.9163	11	2	0.0921
july	82	274	4.8978	1.6387	10	1	-0.5476
july	83	273	4.8352	1.9247	10	1	-0.6102
july	84	258	5.5116	1.7224	12	2	0.0662
july	85	265	5.3283	1.6451	10	2	-0.1171
july	86	255	5.5529	1.8153	11	2	0.1075
july	87	268	5.3955	1.7461	10	2	-0.0499

july	88	274	5.4343	1.9209	10	2	-0.0111
july	89	272	5.2132	1.6296	10	2	-0.2322
july	90	277	5.9783	1.6262	11	0	0.5329
july	91	270	5.5519	1.4335	13	2	0.1065
july	92	259	6.3282	2.0883	11	1	0.8828
july	93	277	5.2635	1.2822	10	2	-0.1819
july	94	242	5.5496	2.0185	18	2	0.1042
july	80-94	3913	5.4454	1.7806	18	0	0
aug	80	269	5.2379	1.6008	11	2	0.1668
aug	81	254	5.189	2.2289	14	0	0.1179
aug	82	257	4.716	1.8331	10	1	-0.3551
aug	83	245	4.7184	1.8769	11	1	-0.3527
aug	84	269	4.4498	1.7327	8	1	-0.6213
aug	85	267	5.1648	2.3062	14	1	0.0937
aug	86	261	5.6015	1.9141	15	2	0.5304
aug	87	269	5.3383	1.548	9	2	0.2672
aug	88	268	5.0373	1.9884	14	1	-0.0338
aug	89	269	4.9108	1.5379	9	1	-0.1603
aug	90	278	5.0612	1.8065	11	1	-0.0099
aug	91	266	4.688	1.5651	10	1	-0.3831
aug	92	265	5.683	2.4366	19	2	0.6119
aug	93	276	4.9312	1.62	12	1	-0.1399
aug	94	241	5.3527	2.1938	15	1	0.2816
aug	80-94	3954	5.0711	1.9223	19	0	0
sept	80	244	5.0615	1.8593	12	1	-0.1553
sept	81	251	4.5737	2.0894	10	0	-0.6431
sept	82	257	4.9494	1.9728	11	1	-0.2674
sept	83	247	5.3077	2.0409	12	2	0.0909
sept	84	245	5.7551	2.7216	15	1	0.5383
sept	85	245	5.3673	2.5551	14	1	0.1505
sept	86	249	5.1928	1.8014	12	1	-0.024
sept	87	227	4.7445	1.6844	9	1	-0.4723
sept	88	241	5.4564	2.1465	13	1	0.2396
sept	89	225	5.4844	3.3019	26	1	0.2676
sept	90	256	5.0547	2.0323	10	1	-0.1621
sept	91	264	4.947	2.0685	14	1	-0.2698
sept	92	254	5.5827	2.407	20	1	0.3659
sept	93	260	5.5385	2.1939	13	1	0.3217
sept	94	229	5.2533	2.0935	11	1	0.0365
sept	80-94	3694	5.2168	2.2449	26	0	0
oct	80	228	5.4167	2.8326	14	1	0.057
oct	81	215	6.0279	2.8084	14	1	0.6682
oct	82	193	5.0725	2.2581	13	1	-0.2872
oct	83	234	5.3932	2.5167	13	1	0.0335
oct	84	257	4.6342	2.121	11	0	-0.7255
oct	85	190	5.2895	2.2899	11	1	-0.0702
oct	86	252	4.8373	2.2479	14	0	-0.5224
oct	87	264	5.4053	2.767	17	1	0.0456
oct	88	259	5.1004	2.0359	12	1	-0.2593
oct	89	253	5.5494	2.4742	15	0	0.1897
oct	90	252	5.5595	3.0298	16	1	0.1998
oct	91	275	5.4109	2.5478	13	1	0.0512
oct	92	262	5.2672	2.4317	21	1	-0.0925
oct	93	248	5.7702	2.9241	20	0	0.4105
oct	94	213	5.77	2.984	17	0	0.4103
oct	80-94	3595	5.3597	2.5875	21	0	0

variable=average relative humidity

month	year	n	average	std. dev.	maximum	minimum	deviation
april	80	120	67.5417	14.6534	99	39	1.6532
april	81	219	66.2192	13.7176	95	33	0.3307
april	82	227	66.4053	17.3917	99	29	0.5168
april	83	220	66.4636	15.0054	97	40	0.5751
april	84	225	68.7689	14.0979	95	37	2.8804
april	85	259	62.3089	14.0411	97	37	-3.5796
april	86	250	57.588	12.6387	94	33	-8.3005
april	87	235	65.9234	14.6095	95	35	0.0349
april	88	244	64.4057	15.5784	99	32	-1.4828
april	89	243	68.2263	12.3182	96	47	2.3378
april	90	245	66.8122	14.3343	98	42	0.9237
april	91	233	74.6996	15.7383	99	35	8.8111
april	92	262	66.2176	13.2452	95	41	0.3291
april	93	230	62.6435	13.3555	93	37	-3.245
april	94	223	65.9148	15.5009	99	32	0.0263
april	80-94	3435	65.8885	14.8584	99	29	0
may	80	144	75.9236	11.818	98	44	2.7497
may	81	212	69.934	12.6242	99	47	-3.2399
may	82	248	74.0524	13.9974	99	45	0.8785
may	83	239	70.6695	11.0535	93	44	-2.5044
may	84	250	70.624	12.569	98	42	-2.5499
may	85	252	74.7302	10.3083	96	49	1.5563
may	86	253	72.1739	15.8054	99	35	-1
may	87	268	77.8881	10.4911	99	45	4.7142
may	88	268	69.4813	13.2049	95	44	-3.6926
may	89	262	70.9122	11.4177	98	46	-2.2617
may	90	250	73	11.5984	97	42	-0.1739
may	91	246	80.1423	10.2734	97	45	6.9684
may	92	244	74.0123	13.7324	100	34	0.8384
may	93	255	74.3294	10.2789	96	50	1.1555
may	94	227	70.1718	11.7523	100	44	-3.0021
may	80-94	3618	73.1739	12.5114	100	34	0
june	80	184	74.7609	11.7109	100	45	-0.5167
june	81	246	76.0732	11.047	98	45	0.7956
june	82	256	80.0547	9.1208	100	55	4.7771
june	83	241	75.1411	9.6521	94	49	-0.1365
june	84	243	70.9835	8.477	97	48	-4.2941
june	85	260	74.4577	10.508	97	51	-0.8199
june	86	254	73.0551	10.2828	97	47	-2.2225
june	87	262	77.3702	12.8849	96	49	2.0926
june	88	253	65.5494	11.034	93	43	-9.7282
june	89	263	80.6844	9.0938	96	61	5.4068
june	90	260	70.5231	8.7507	91	52	-4.7545
june	91	263	76.9316	10.1783	97	53	1.654
june	92	252	79.4365	9.2072	97	62	4.1589
june	93	267	73.0262	9.4799	94	53	-2.2514
june	94	232	81.2069	8.1825	97	50	5.9293
june	80-94	3736	75.2776	10.8515	100	43	0
july	80	209	79.0048	9.2718	98	54	1.0434
july	81	240	77.7333	8.5831	96	57	-0.2281
july	82	274	83.8978	7.1645	96	59	5.9364
july	83	273	73.9194	8.1087	93	52	-4.042
july	84	258	78.7016	8.7494	97	60	0.7402
july	85	265	80.8755	9.3255	97	61	2.9141
july	86	255	71.8314	11.7808	94	46	-6.13
july	87	268	76.403	9.5145	96	55	-1.5584

july	88	274	77.2044	11.5357	96	37	-0.757
july	89	272	80.7353	8.1971	96	60	2.7739
july	90	277	74.6787	10.7916	98	53	-3.2827
july	91	270	80.8519	8.7319	97	56	2.8905
july	92	259	78.7954	9.6874	98	58	0.834
july	93	277	72.1047	10.1835	95	49	-5.8567
july	94	242	83.4132	6.6134	98	67	5.4518
july	80-94	3913	77.9614	10.0019	98	37	0
aug	80	269	76.5019	8.2093	98	57	-3.2209
aug	81	254	78.8268	6.7655	96	65	-0.896
aug	82	257	82.5019	7.5716	97	60	2.7791
aug	83	245	74.5469	9.2197	95	55	-5.1759
aug	84	269	82.1747	7.0226	98	66	2.4519
aug	85	267	81.8202	7.3253	96	63	2.0974
aug	86	261	80.9425	10.6454	99	54	1.2197
aug	87	269	76.4126	9.7202	98	53	-3.3102
aug	88	268	79.5336	9.0274	97	58	-0.1892
aug	89	269	82.0967	8.1469	97	58	2.3739
aug	90	278	77.5396	9.2937	97	57	-2.1832
aug	91	266	82.1429	8.2138	96	60	2.4201
aug	92	265	82.4528	8.4387	98	53	2.73
aug	93	276	76.6957	8.8286	95	40	-3.0271
aug	94	241	81.7469	7.0709	98	67	2.0241
aug	80-94	3954	79.7228	8.834	99	40	0
sept	80	244	82.4139	10.8683	100	57	3.3221
sept	81	251	76.9721	8.9775	96	47	-2.1197
sept	82	257	80.4708	8.8043	98	60	1.379
sept	83	247	74.4777	9.1624	96	53	-4.6141
sept	84	245	73.6	8.6977	94	52	-5.4918
sept	85	245	76.0571	8.4162	90	55	-3.0347
sept	86	249	84.5904	8.3633	100	62	5.4986
sept	87	227	80.8899	10.1079	99	57	1.7981
sept	88	241	82.9295	8.4157	98	64	3.8377
sept	89	225	82.9156	8.2828	99	57	3.8238
sept	90	256	75.25	9.1921	96	55	-3.8418
sept	91	264	77.3788	8.6614	98	57	-1.713
sept	92	254	84.1693	8.2977	99	57	5.0775
sept	93	260	75.3231	12.1929	98	45	-3.7687
sept	94	229	79.786	8.2554	99	60	0.6942
sept	80-94	3694	79.0918	9.8712	100	45	0
oct	80	228	81.1447	11.4569	100	50	4.807
oct	81	215	69.6512	11.2957	100	45	-6.6865
oct	82	193	78.1295	10.9511	97	51	1.7918
oct	83	234	76.859	10.5815	98	50	0.5213
oct	84	257	82.5798	9.5157	99	43	6.2421
oct	85	190	79.9053	10.8633	100	41	3.5676
oct	86	252	81.0119	9.8055	100	49	4.6742
oct	87	264	66.7841	12.2283	92	36	-9.5536
oct	88	259	72.834	11.5265	97	42	-3.5037
oct	89	253	76.0237	11.8716	98	46	-0.314
oct	90	252	77.2738	11.0519	98	51	0.9361
oct	91	275	74.2691	10.9341	99	49	-2.0686
oct	92	262	77.2595	9.7514	99	49	0.9218
oct	93	248	74.996	12.632	99	46	-1.3417
oct	94	213	77.9671	10.5988	100	52	1.6294
oct	80-94	3595	76.3377	11.7932	100	36	0

variable=average dewpoint temperature

month	year	n	average	std. dev.	maximum	minimum	deviation
april	80	120	45.2114	8.6616	63.6106	25.8475	0.8566
april	81	219	48.3798	9.5733	64.257	27.0395	4.025
april	82	227	41.5759	11.9015	63.2992	10.7266	-2.7789
april	83	220	39.1814	10.726	61.842	16.8396	-5.1734
april	84	225	43.0492	9.563	66.2648	26.5609	-1.3056
april	85	259	44.688	11.3778	62.6488	14.9589	0.3332
april	86	250	42.7114	9.7468	60.0228	19.7278	-1.6434
april	87	235	42.2726	10.9373	62.3466	17.2882	-2.0822
april	88	244	43.4498	9.6394	66.9336	28.3175	-0.905
april	89	243	45.1548	11.0915	63.8321	21.1771	0.8
april	90	245	44.7066	11.3091	61.9188	20.0768	0.3518
april	91	233	51.2385	10.0132	67.57	28.7379	6.8837
april	92	262	44.6487	12.229	65.9014	14.9922	0.2939
april	93	230	41.3443	8.838	61.3287	25.8475	-3.0105
april	94	223	48.1399	11.4914	67.8835	27.3568	3.7851
april	80-94	3435	44.3548	10.9907	67.8835	10.7266	0
may	80	144	56.3857	8.3937	69.8022	31.483	1.0278
may	81	212	51.4422	8.2321	67.3074	28.7329	-3.9157
may	82	248	57.685	8.1876	71.8532	36.2428	2.3271
may	83	239	52.3808	8.0574	67.2534	33.9332	-2.9771
may	84	250	51.9264	9.6381	67.9214	27.8122	-3.4315
may	85	252	56.1955	6.3849	67.5488	39.2801	0.8376
may	86	253	55.3567	9.8982	69.4906	25.1186	-0.0012
may	87	268	60.1249	7.0734	72.1909	39.1199	4.767
may	88	268	52.8724	6.8743	68.9044	36.9788	-2.4855
may	89	262	53.0505	9.2969	68.9275	31.9717	-2.3074
may	90	250	55.7839	7.9614	67.57	37.9078	0.426
may	91	246	63.0889	7.3496	72.8561	39.5204	7.731
may	92	244	53.6494	7.2502	66.5802	35.9653	-1.7085
may	93	255	57.0923	6.0084	66.209	40.9443	1.7344
may	94	227	52.8163	7.4051	69.1094	36.4064	-2.5416
may	80-94	3618	55.3579	8.5294	72.8561	25.1186	0
june	80	184	62.0419	7.3942	75.4378	42.7558	-1.9049
june	81	246	66.5973	5.0957	73.8189	49.6063	2.6505
june	82	256	64.1291	4.0047	71.5395	54.5524	0.1823
june	83	241	61.5776	6.1915	71.445	47.4755	-2.3692
june	84	243	62.2995	5.4613	70.857	41.3788	-1.6473
june	85	260	62.963	6.3816	70.965	43.7596	-0.9838
june	86	254	65.2027	4.5612	72.9072	49.9825	1.2559
june	87	262	65.2187	5.819	72.1956	49.7369	1.2719
june	88	253	59.297	7.2714	71.3352	41.0722	-4.6498
june	89	263	66.337	3.1381	74.1593	56.2301	2.3902
june	90	260	63.0439	5.5697	72.6755	47.8962	-0.9029
june	91	263	65.1593	6.4072	73.2804	49.8782	1.2125
june	92	252	62.7777	5.6489	71.4833	44.9527	-1.1691
june	93	267	64.0848	4.7181	72.5297	47.8375	0.138
june	94	232	68.0338	3.4767	74.3762	49.6063	4.087
june	80-94	3736	63.9468	5.9049	75.4378	41.0722	0
july	80	209	69.1937	3.4222	76.042	56.3373	0.8843
july	81	240	68.4161	3.8544	76.9412	54.0845	0.1067
july	82	274	69.4333	3.0594	75.4378	55.5552	1.1239
july	83	273	66.8233	5.0394	76.7672	51.2767	-1.4861
july	84	258	65.17	3.6759	72.148	52.8343	-3.1394
july	85	265	67.2205	3.1934	73.0944	57.8316	-1.0889
july	86	255	68.4642	3.907	76.3301	56.1654	0.1548
july	87	268	68.5585	3.4282	74.0148	58.6561	0.2491

july	88	274	67.6	5.75	75.3532	41.6661	-0.7094
july	89	272	68.3702	3.0887	76.0675	57.3723	0.0608
july	90	277	67.1476	3.5573	73.1277	56.8899	-1.1618
july	91	270	70.3671	2.8694	75.2254	57.2765	2.0577
july	92	259	69.2073	2.8119	74.3762	59.2154	0.8979
july	93	277	69.4241	3.5186	75.0517	55.0187	1.1147
july	94	242	69.4766	2.281	72.7767	59.4122	1.1672
july	80-94	3913	68.3094	3.8899	76.9412	41.6661	0
aug	80	269	68.4023	3.6728	75.0876	58.7307	1.0702
aug	81	254	65.2213	4.5978	75.458	51.1552	-2.1108
aug	82	257	66.7643	4.0733	73.8302	49.2384	-0.5678
aug	83	245	67.4979	4.0994	72.6755	53.122	0.1658
aug	84	269	66.9488	3.5279	73.5108	55.6931	-0.3833
aug	85	267	66.4047	3.9707	72.6755	54.5907	-0.9274
aug	86	261	66.4873	6.0324	72.1956	40.9916	-0.8448
aug	87	269	68.3638	4.505	75.3532	53.5378	1.0317
aug	88	268	69.6343	3.6081	74.4964	54.1926	2.3022
aug	89	269	67.7618	5.364	74.8301	50.5788	0.4297
aug	90	278	67.4556	3.7367	74.4964	54.7403	0.1235
aug	91	266	68.1172	4.0374	75.4819	55.1473	0.7851
aug	92	265	65.6352	3.9118	74.0148	54.5007	-1.6969
aug	93	276	67.816	3.2458	74.0111	51.7544	0.4839
aug	94	241	67.2797	3.2851	72.5251	58.7498	-0.0524
aug	80-94	3954	67.3321	4.3085	75.4819	40.9916	0
sept	80	244	66.0662	6.0337	73.8431	47.0671	4.8859
sept	81	251	58.1102	8.6188	70.7972	38.6688	-3.0701
sept	82	257	59.5982	7.1412	72.5189	41.1954	-1.5821
sept	83	247	58.4001	10.4092	73.0393	34.7832	-2.7802
sept	84	245	56.2406	7.389	71.1716	41.8842	-4.9397
sept	85	245	58.3525	9.3293	72.0637	37.5006	-2.8278
sept	86	249	64.6478	5.0626	71.5291	49.2819	3.4675
sept	87	227	62.6625	6.3422	73.4707	45.6706	1.4822
sept	88	241	62.7317	6.1117	72.5251	46.512	1.5514
sept	89	225	63.4067	7.6646	72.5251	37.486	2.2264
sept	90	256	61.0827	8.5261	72.5189	39.0962	-0.0976
sept	91	264	61.1977	9.5758	75.9658	37.9078	0.0174
sept	92	254	63.4713	7.2106	71.7922	40.7294	2.291
sept	93	260	61.7196	9.1069	72.9072	35.8782	0.5393
sept	94	229	60.3002	5.8978	72.1477	48.4389	-0.8801
sept	80-94	3694	61.1803	8.2266	75.9658	34.7832	0
oct	80	228	49.0155	9.7535	70.1057	26.1103	-0.2164
oct	81	215	44.8165	8.8779	65.6249	22.5184	-4.4154
oct	82	193	50.1458	11.6856	70.5394	31.4201	0.9139
oct	83	234	49.6754	8.3934	68.2535	32.2108	0.4435
oct	84	257	57.3568	7.483	68.2418	34.944	8.1249
oct	85	190	54.9586	8.4026	67.5085	30.6748	5.7267
oct	86	252	53.0018	9.6579	70.5307	35.859	3.7699
oct	87	264	40.0213	7.3684	56.0732	21.6624	-9.2106
oct	88	259	43.4405	9.4013	66.8925	26.0016	-5.7914
oct	89	253	49.4092	10.5115	70.1792	26.6941	0.1773
oct	90	252	51.0141	11.3637	70.4896	28.4343	1.7822
oct	91	275	49.5358	9.3522	67.2691	31.2174	0.3039
oct	92	262	47.9401	8.0164	65.217	23.3006	-1.2918
oct	93	248	49.171	9.43	67.57	30.9509	-0.0609
oct	94	213	50.6389	8.7278	67.202	31.6238	1.407
oct	80-94	3595	49.2319	10.1784	70.5394	21.6624	0

variable=average dewpoint temperature depression

month	year	n	average	std. dev.	maximum	minimum	deviation
april	80	120	11.1552	5.8341	25.6478	0.2772	-0.6722
april	81	219	11.8028	5.7145	29.2996	1.4051	-0.0246
april	82	227	11.7061	7.2248	31.9425	0.2549	-0.1213
april	83	220	11.2913	5.7944	24.38	0.8499	-0.5361
april	84	225	10.4752	5.4583	25.8999	1.3929	-1.3522
april	85	259	13.3274	5.7359	26.4243	0.8463	1.5
april	86	250	15.4286	5.7275	28.4405	1.6502	3.6012
april	87	235	11.7359	6.1518	29.2405	1.399	-0.0915
april	88	244	12.5215	6.5277	29.812	0.2796	0.6941
april	89	243	10.6929	4.7735	19.5267	1.1679	-1.1345
april	90	245	11.3628	5.5616	21.7095	0.5592	-0.4646
april	91	233	8.6156	6.2881	27.2621	0.2748	-3.2118
april	92	262	11.5117	5.1507	22.9684	1.4665	-0.3157
april	93	230	12.9904	5.5197	26.778	2.0286	1.163
april	94	223	12.0619	6.5158	31.1909	0.2893	0.2345
april	80-94	3435	11.8274	6.0578	31.9425	0.2549	0
may	80	144	8.031	4.3993	21.7799	0.5836	-1.102
may	81	212	10.2984	4.9813	20.0212	0.2869	1.1654
may	82	248	8.9642	5.495	22.3868	0.2893	-0.1688
may	83	239	9.9121	4.2955	22.6119	2.0986	0.7791
may	84	250	9.9896	4.9116	23.1463	0.5738	0.8566
may	85	252	8.4395	3.943	19.6342	1.1531	-0.6935
may	86	253	9.7895	6.4512	27.0336	0.2724	0.6565
may	87	268	7.3639	3.9206	21.5695	0.293	-1.7691
may	88	268	10.609	5.304	22.1479	1.4111	1.476
may	89	262	9.8693	4.3936	21.3546	0.5641	0.7363
may	90	250	9.1681	4.5379	23.7306	0.8646	0.0351
may	91	246	6.594	3.8202	21.4796	0.8282	-2.539
may	92	244	8.9039	5.6376	29.0347	0	-0.2291
may	93	255	8.6293	3.9029	19.1546	1.1286	-0.5037
may	94	227	10.2233	4.7025	22.4258	0	1.0903
may	80-94	3618	9.133	4.8966	29.0347	0	0
june	80	184	8.7027	4.522	22.0218	0	0.1602
june	81	246	8.3458	4.4137	22.9396	0.591	-0.1967
june	82	256	6.6287	3.3895	17.1708	0	-1.9138
june	83	241	8.4307	3.7059	20.1824	1.7905	-0.1118
june	84	243	10.1037	3.355	20.8254	0.8757	1.5612
june	85	260	8.8062	4.0909	18.7064	0.8868	0.2637
june	86	254	9.4705	4.1533	22.0998	0.8943	0.928
june	87	262	7.8691	5.0383	20.1824	1.1978	-0.6734
june	88	253	12.5211	4.7544	22.9278	2.0286	3.9786
june	89	263	6.4767	3.4006	14.2854	1.1878	-2.0658
june	90	260	10.3523	3.5574	18.6426	2.7352	1.8098
june	91	263	7.8673	3.8582	18.046	0.898	-0.6752
june	92	252	6.8096	3.3428	13.7723	0.8646	-1.7329
june	93	267	9.4096	3.8397	18.3433	1.798	0.8671
june	94	232	6.2895	3.1429	19.41	0.8683	-2.253
june	80-94	3736	8.5425	4.2618	22.9396	0	0
july	80	209	7.2035	3.5962	18.4818	0.596	-0.4109
july	81	240	7.6422	3.3578	15.9534	1.2179	0.0278
july	82	274	5.2966	2.6185	15.5317	1.2028	-2.3178
july	83	273	9.0631	3.2055	18.4903	2.1519	1.4487
july	84	258	7.1556	3.2416	14.3877	0.8868	-0.4588
july	85	265	6.4323	3.4506	14.1684	0.9056	-1.1821
july	86	255	10.2496	5.0268	23.3412	1.8208	2.6352
july	87	268	8.2027	3.7566	17.5236	1.2078	0.5883

july	88	274	7.973	4.7734	27.3339	1.1978	0.3586
july	89	272	6.4681	3.0984	14.6277	1.1928	-1.1463
july	90	277	8.9173	4.2806	18.7936	0.5935	1.3029
july	91	270	6.507	3.3241	17.2212	0.9018	-1.1074
july	92	259	7.2985	3.7371	15.7596	0.596	-0.3159
july	93	277	10.0561	4.2935	20.5141	1.5167	2.4417
july	94	242	5.4572	2.3727	11.7356	0.5861	-2.1572
july	80-94	3913	7.6144	3.96	27.3339	0.5861	0
aug	80	269	8.0995	3.202	16.3787	0.5935	1.2578
aug	81	254	7.0307	2.4709	12.5163	1.1778	0.189
aug	82	257	5.7376	2.7218	14.3281	0.8906	-1.1041
aug	83	245	8.9021	3.6881	17.5946	1.4978	2.0604
aug	84	269	5.843	2.4738	11.8681	0.596	-0.9987
aug	85	267	5.9735	2.6298	13.0514	1.2078	-0.8682
aug	86	261	6.4284	3.9797	18.0415	0.2905	-0.4133
aug	87	269	8.1901	3.8021	18.4928	0.596	1.3484
aug	88	268	6.9926	3.4574	15.7596	0.9093	0.1509
aug	89	269	5.9223	2.9104	15.3754	0.8868	-0.9194
aug	90	278	7.6991	3.5468	16.4454	0.9018	0.8574
aug	91	266	5.9279	2.9938	14.6277	1.2078	-0.9138
aug	92	265	5.7761	3.116	18.418	0.5935	-1.0656
aug	93	276	8.0391	3.5386	26.2456	1.4728	1.1974
aug	94	241	6.019	2.5358	11.7356	0.591	-0.8227
aug	80-94	3954	6.8417	3.3424	26.2456	0.2905	0
sept	80	244	5.8928	3.9419	16.3122	0	-1.0062
sept	81	251	7.5432	3.2693	20.2757	1.2028	0.6442
sept	82	257	6.3162	3.1156	14.688	0.5812	-0.5828
sept	83	247	8.523	3.3713	18.1201	1.158	1.624
sept	84	245	8.8124	3.3936	18.1943	1.783	1.9134
sept	85	245	7.8801	3.12	16.6826	3.0792	0.9811
sept	86	249	4.9747	2.9108	13.6028	0	-1.9243
sept	87	227	6.2935	3.623	15.6537	0.2893	-0.6055
sept	88	241	5.5048	2.9156	12.6183	0.5787	-1.3942
sept	89	225	5.5133	2.8578	14.9446	0.2844	-1.3857
sept	90	256	8.3314	3.3945	16.4067	1.1978	1.4324
sept	91	264	7.4728	3.0808	15.2006	0.5763	0.5738
sept	92	254	5.0641	2.8252	15.0084	0.2869	-1.8349
sept	93	260	8.4766	4.6821	21.1218	0.596	1.5776
sept	94	229	6.5731	2.9437	14.2685	0.2905	-0.3259
sept	80-94	3694	6.899	3.576	21.1218	0	0
oct	80	228	5.8836	3.9232	18.6806	0	-1.7346
oct	81	215	10.0114	4.2591	20.9439	0	2.3932
oct	82	193	6.9008	3.7447	17.7121	0.8757	-0.7174
oct	83	234	7.3973	3.7737	18.6022	0.5861	-0.2209
oct	84	257	5.5459	3.4294	22.6433	0.282	-2.0723
oct	85	190	6.4782	4.0402	24.0553	0	-1.14
oct	86	252	6.0061	3.5168	19.3643	0	-1.6121
oct	87	264	11.0847	5.0919	26.7963	2.2307	3.4665
oct	88	259	8.6985	4.1871	21.9984	0.8757	1.0803
oct	89	253	7.7371	4.3254	20.6531	0.5617	0.1189
oct	90	252	7.2557	3.8214	17.262	0.5763	-0.3625
oct	91	275	8.3587	4.0003	18.5239	0.2856	0.7405
oct	92	262	7.1477	3.393	17.6994	0.2784	-0.4705
oct	93	248	8.2	4.7235	20.7402	0.2832	0.5818
oct	94	213	6.9996	3.6845	17.5894	0	-0.6186
oct	80-94	3595	7.6182	4.2855	26.7963	0	0

variable=average mean sea level pressure

month	year	n	average	std. dev.	maximum	minimum	deviation
april	80	120	1013.77	5.84	1025.7	1003.7	-2.59
april	81	219	1019.41	6.38	1036.1	1002.6	3.05
april	82	227	1018.53	5.44	1032.3	1002	2.17
april	83	220	1013.41	5.63	1022.7	993	-2.95
april	84	225	1012.74	6.17	1023.3	998.6	-3.62
april	85	259	1018.11	5.55	1029.4	1006.7	1.75
april	86	250	1015.52	5.03	1025.2	1002.9	-0.84
april	87	235	1013.66	4.86	1023.3	999.6	-2.7
april	88	244	1012.93	4.88	1023.5	997.9	-3.43
april	89	243	1017.14	4.67	1029.4	1008.7	0.78
april	90	245	1019.08	6.78	1035.3	1005.9	2.72
april	91	233	1017.68	6.09	1034.2	1004.5	1.32
april	92	262	1017.21	4.6	1029	1006	0.85
april	93	230	1015.72	5.8	1028.2	1001.5	-0.64
april	94	223	1019.12	4.21	1029.7	1010.3	2.76
april	80-94	3435	1016.36	5.95	1036.1	993	0
may	80	144	1014.28	4.2	1026.8	1005	-2.22
may	81	212	1014.23	3.49	1020.2	1007.2	-2.27
may	82	248	1017.33	3.23	1024.1	1010	0.83
may	83	239	1016.04	4.8	1028.6	1004.7	-0.46
may	84	250	1017.35	4.8	1026.5	997.3	0.85
may	85	252	1014.65	4	1023	1001.4	-1.85
may	86	253	1016.47	3.5	1026.6	1010.2	-0.03
may	87	268	1018.9	3.3	1025	1011.1	2.4
may	88	268	1015.58	3.62	1023	1008.1	-0.92
may	89	262	1016.47	4.29	1026.4	1007.2	-0.03
may	90	250	1015.68	4.19	1024.5	1003.3	-0.82
may	91	246	1018.68	4.02	1027.9	1011.3	2.18
may	92	244	1018	4.72	1028.9	1009.9	1.5
may	93	255	1016.24	4.74	1023.8	1005	-0.26
may	94	227	1016.23	3.37	1024.6	1007.3	-0.27
may	80-94	3618	1016.5	4.27	1028.9	997.3	0
june	80	184	1016.29	3.04	1025	1008.6	0.31
june	81	246	1015.81	4.18	1026.3	1005.5	-0.17
june	82	256	1014.24	2.79	1020.7	1007	-1.74
june	83	241	1016.3	3.49	1024.4	1007.9	0.32
june	84	243	1017.25	3.15	1022.5	1010.6	1.27
june	85	260	1015.06	2.82	1021.3	1007.4	-0.92
june	86	254	1016.28	3.06	1022.9	1009.1	0.3
june	87	262	1016.78	3.7	1023.9	1008.7	0.8
june	88	253	1016.39	5.12	1026.2	1003.7	0.41
june	89	263	1016.32	3.16	1022.2	1007.4	0.34
june	90	260	1016.69	3.53	1025.6	1007.5	0.71
june	91	263	1016.85	4.4	1025.1	1006.5	0.87
june	92	252	1013.34	3.75	1023.5	1005.2	-2.64
june	93	267	1017.01	3.81	1025.1	1007.4	1.03
june	94	232	1015.07	3.49	1022.4	1004.4	-0.91
june	80-94	3736	1015.98	3.78	1026.3	1003.7	0
july	80	209	1015.74	2.53	1021.5	1011.1	-1.39
july	81	240	1016.82	3.32	1024.3	1009.5	-0.31
july	82	274	1017.44	2.44	1022.6	1010.8	0.31
july	83	273	1017.91	3.22	1026.3	1010.6	0.78
july	84	258	1017.19	2.82	1023.4	1010.5	0.06
july	85	265	1016.91	2.16	1020.8	1011.4	-0.22
july	86	255	1016.84	3.41	1024.1	1010	-0.29
july	87	268	1017.83	3.17	1025.3	1009.9	0.7

july	88	274	1018.1	2.91	1025.8	1009.8	0.97
july	89	272	1017.73	3.93	1026.6	1008.3	0.6
july	90	277	1017.71	3.31	1025.9	1011.3	0.58
july	91	270	1016.09	2.85	1023.6	1011	-1.04
july	92	259	1016.64	2.73	1022	1009.9	-0.49
july	93	277	1016.24	1.61	1019.7	1012	-0.89
july	94	242	1017.38	2.87	1022.8	1009.5	0.25
july	80-94	3913	1017.13	3.01	1026.6	1008.3	0
aug	80	269	1017.26	3.1	1023.2	1010.7	-0.26
aug	81	254	1017.33	3.4	1025.7	1007.8	-0.19
aug	82	257	1018.2	2.39	1027	1013.4	0.68
aug	83	245	1017.6	3.23	1025.9	1009.5	0.08
aug	84	269	1016.94	3.31	1024.1	1009.9	-0.58
aug	85	267	1018.37	3.33	1026.4	1011	0.85
aug	86	261	1017.26	3.47	1027.8	1010.1	-0.26
aug	87	269	1016.97	3.68	1024.3	1008.8	-0.55
aug	88	268	1016.52	3.25	1022.5	1009.7	-1
aug	89	269	1016.82	2.97	1022.9	1006.2	-0.7
aug	90	278	1017.27	2.15	1021.7	1010.5	-0.25
aug	91	266	1017.69	3.36	1025.7	1009.4	0.17
aug	92	265	1018.82	3.42	1027.2	1008.4	1.3
aug	93	276	1017.45	2.75	1024.7	1011.6	-0.07
aug	94	241	1018.46	3.1	1025.3	1010.1	0.94
aug	80-94	3954	1017.52	3.21	1027.8	1006.2	0
sept	80	244	1018.38	3.08	1025.7	1009.4	-0.51
sept	81	251	1017.41	3.57	1026.3	1010.3	-1.48
sept	82	257	1018.52	3.6	1025.6	1010.5	-0.37
sept	83	247	1019.96	4.6	1032.2	1011.9	1.07
sept	84	245	1019.89	4.15	1029.8	1011.3	1
sept	85	245	1021.14	4.77	1032.4	1003.6	2.25
sept	86	249	1020.46	3.45	1028.3	1013.3	1.57
sept	87	227	1016.54	3.49	1025.9	1009.3	-2.35
sept	88	241	1018.53	4.57	1028.3	1004.5	-0.36
sept	89	225	1017.88	4.08	1031	1006.2	-1.01
sept	90	256	1018.02	3.82	1026.5	1008.6	-0.87
sept	91	264	1020.31	4.65	1029.6	1006.3	1.42
sept	92	254	1020.13	3.53	1026.9	1010.8	1.24
sept	93	260	1017.74	3.36	1026.7	1010.3	-1.15
sept	94	229	1018.05	4	1024.6	1009.1	-0.84
sept	80-94	3694	1018.89	4.15	1032.4	1003.6	0
oct	80	228	1017.65	4.89	1027.3	1009.3	-2.55
oct	81	215	1020.8	4.94	1032.9	1008	0.6
oct	82	193	1020.76	4.97	1030.3	1009.8	0.56
oct	83	234	1020.71	4.98	1033.7	1008.8	0.51
oct	84	257	1021.28	3.92	1031.3	1009.2	1.08
oct	85	190	1020.66	4.73	1032.5	1003.5	0.46
oct	86	252	1020.9	4.56	1031.2	1009.5	0.7
oct	87	264	1021.8	5.25	1030.8	1008.9	1.6
oct	88	259	1020.5	5.66	1030.9	1007.9	0.3
oct	89	253	1020.62	4.79	1030.6	1010.4	0.42
oct	90	252	1019.23	4.94	1028.4	1007.4	-0.97
oct	91	275	1020.1	5.08	1030.1	1006.4	-0.1
oct	92	262	1019.73	5.53	1032.3	1010.9	-0.47
oct	93	248	1019.03	5.24	1029.5	1002.5	-1.17
oct	94	213	1019.05	4.11	1029.2	1004	-1.15
oct	80-94	3595	1020.2	5.04	1033.7	1002.5	0

variable=average Pasquill Stability Index

month	year	n	average	std. dev.	maximum	minimum	deviation
april	80	120	4.74	0.5863	6.2	3.8	0.0296
april	81	219	4.7416	0.508	5.9	3.9	0.0312
april	82	227	4.5577	0.536	6.1	3.9	-0.1527
april	83	220	4.6905	0.5872	6.2	3.7	-0.0199
april	84	225	4.6218	0.5635	6.1	3.9	-0.0886
april	85	259	4.8019	0.5333	5.9	3.9	0.0915
april	86	250	4.92	0.5067	5.9	3.9	0.2096
april	87	235	4.6791	0.5318	5.8	3.9	-0.0313
april	88	244	4.673	0.521	5.7	3.9	-0.0374
april	89	243	4.6642	0.5658	5.9	3.8	-0.0462
april	90	245	4.758	0.5378	6.1	3.8	0.0476
april	91	233	4.6146	0.5623	6.1	3.9	-0.0958
april	92	262	4.7076	0.4835	5.8	3.9	-0.0028
april	93	230	4.6809	0.5322	5.7	3.9	-0.0295
april	94	223	4.7933	0.5597	6.1	3.9	0.0829
april	80-94	3435	4.7104	0.5453	6.2	3.7	0
may	80	144	4.6687	0.5091	5.9	3.8	0.0174
may	81	212	4.6302	0.5224	5.9	3.8	-0.0211
may	82	248	4.7472	0.5232	6	3.7	0.0959
may	83	239	4.6163	0.5519	5.7	3.8	-0.035
may	84	250	4.6656	0.5184	5.8	3.8	0.0143
may	85	252	4.6702	0.5221	5.8	3.8	0.0189
may	86	253	4.6478	0.5165	5.9	3.7	-0.0035
may	87	268	4.6731	0.4608	5.8	3.9	0.0218
may	88	268	4.7907	0.4782	5.8	3.9	0.1394
may	89	262	4.6374	0.4659	5.6	3.9	-0.0139
may	90	250	4.488	0.4527	5.6	3.9	-0.1633
may	91	246	4.5325	0.4699	5.9	3.8	-0.1188
may	92	244	4.6279	0.4966	5.8	3.8	-0.0234
may	93	255	4.6796	0.4932	5.7	3.8	0.0283
may	94	227	4.6863	0.4601	5.6	3.9	0.035
may	80-94	3618	4.6513	0.5003	6	3.7	0
june	80	184	4.6538	0.4373	5.6	3.9	0.043
june	81	246	4.5874	0.4611	5.8	3.8	-0.0234
june	82	256	4.6152	0.4593	5.8	3.7	0.0044
june	83	241	4.6934	0.5413	5.8	3.7	0.0826
june	84	243	4.7436	0.4008	5.7	3.9	0.1328
june	85	260	4.6062	0.4694	5.5	3.6	-0.0046
june	86	254	4.6567	0.4361	5.7	3.9	0.0459
june	87	262	4.5237	0.4005	5.8	3.8	-0.0871
june	88	253	4.6933	0.4243	5.6	3.7	0.0825
june	89	263	4.4863	0.4502	5.6	3.8	-0.1245
june	90	260	4.6308	0.4143	5.5	3.7	0.02
june	91	263	4.4905	0.4788	5.5	3.8	-0.1203
june	92	252	4.5968	0.4734	5.8	3.8	-0.014
june	93	267	4.6888	0.405	5.6	3.8	0.078
june	94	232	4.5155	0.5102	5.6	3.6	-0.0953
june	80-94	3736	4.6108	0.4577	5.8	3.6	0
july	80	209	4.7325	0.4694	5.8	3.7	0.0912
july	81	240	4.5842	0.4709	5.6	3.8	-0.0571
july	82	274	4.5923	0.4485	6	3.8	-0.049
july	83	273	4.8842	0.3997	5.7	3.7	0.2429
july	84	258	4.5244	0.4771	5.6	3.9	-0.1169
july	85	265	4.5868	0.4945	5.6	3.8	-0.0545
july	86	255	4.7388	0.4002	5.6	3.8	0.0975
july	87	268	4.725	0.4367	5.8	3.8	0.0837

july	88	274	4.6609	0.4727	5.6	3.8	0.0196
july	89	272	4.5375	0.479	5.7	3.7	-0.1038
july	90	277	4.6643	0.4537	5.9	3.9	0.023
july	91	270	4.5181	0.4262	5.3	3.6	-0.1232
july	92	259	4.5637	0.4028	5.7	3.8	-0.0776
july	93	277	4.7256	0.4132	5.7	3.9	0.0843
july	94	242	4.5814	0.4317	5.4	3.9	-0.0599
july	80-94	3913	4.6413	0.4562	6	3.6	0
aug	80	269	4.9164	0.4865	6	3.9	0.1284
aug	81	254	4.6567	0.617	5.9	3.9	-0.1313
aug	82	257	4.8346	0.5628	6.1	3.9	0.0466
aug	83	245	4.8947	0.5204	5.9	3.9	0.1067
aug	84	269	4.9	0.5578	6.1	3.9	0.112
aug	85	267	4.7835	0.6276	6.4	3.8	-0.0045
aug	86	261	4.6943	0.5118	5.9	3.8	-0.0937
aug	87	269	4.7862	0.5014	5.9	3.8	-0.0018
aug	88	268	4.8683	0.5255	5.8	3.9	0.0803
aug	89	269	4.7911	0.5448	5.9	3.9	0.0031
aug	90	278	4.7763	0.539	5.9	3.9	-0.0117
aug	91	266	4.6643	0.5566	6	3.8	-0.1237
aug	92	265	4.6328	0.5911	6.1	3.9	-0.1552
aug	93	276	4.8402	0.5231	6.1	3.8	0.0522
aug	94	241	4.7763	0.5234	5.9	3.7	-0.0117
aug	80-94	3954	4.788	0.5534	6.4	3.7	0
sept	80	244	4.8303	0.5473	5.9	3.9	-0.0892
sept	81	251	5.1048	0.6301	6.1	3.9	0.1853
sept	82	257	4.8444	0.6652	6.4	3.9	-0.0751
sept	83	247	5.0085	0.6046	6.1	4	0.089
sept	84	245	5.0155	0.5827	6	3.9	0.096
sept	85	245	5.1212	0.592	6.1	3.9	0.2017
sept	86	249	4.8892	0.6373	6.1	3.9	-0.0303
sept	87	227	4.8894	0.6427	6.1	3.9	-0.0301
sept	88	241	4.8154	0.6085	6	3.9	-0.1041
sept	89	225	4.7724	0.7056	6.1	3.9	-0.1471
sept	90	256	4.9645	0.5738	6.1	3.9	0.045
sept	91	264	4.9902	0.5805	6.1	3.8	0.0707
sept	92	254	4.7343	0.5671	6	3.9	-0.1852
sept	93	260	4.8685	0.582	6.1	3.8	-0.051
sept	94	229	4.9301	0.6367	6.2	3.9	0.0106
sept	80-94	3694	4.9195	0.6196	6.4	3.8	0
oct	80	228	5.0004	0.6783	6.1	3.9	-0.0016
oct	81	215	4.9386	0.6788	6.2	4	-0.0634
oct	82	193	4.9772	0.7321	6.4	3.9	-0.0248
oct	83	234	4.8966	0.6889	6.3	3.8	-0.1054
oct	84	257	4.8767	0.6564	6.3	3.9	-0.1253
oct	85	190	4.9047	0.7062	6.1	4	-0.0973
oct	86	252	5.031	0.7005	6.3	4	0.029
oct	87	264	5.2098	0.5795	6.2	3.9	0.2078
oct	88	259	5.0853	0.6207	6.1	3.9	0.0833
oct	89	253	5.0296	0.6097	6.1	3.9	0.0276
oct	90	252	5.0813	0.6802	6.4	3.9	0.0793
oct	91	275	5.0753	0.6105	6.1	3.9	0.0733
oct	92	262	5.0752	0.6359	6.3	3.9	0.0732
oct	93	248	4.8625	0.7214	6.7	3.8	-0.1395
oct	94	213	4.9014	0.6923	6.4	3.9	-0.1006
oct	80-94	3595	5.002	0.6702	6.7	3.8	0

variable=minimum Pasquill Stability Index

month	year	n	average	std. dev.	maximum	minimum	deviation
april	80	120	3.125	0.7945	4	2	-0.1251
april	81	219	3.2648	0.7124	4	2	0.0147
april	82	227	3.5198	0.6607	4	2	0.2697
april	83	220	3.3409	0.7133	4	2	0.0908
april	84	225	3.2844	0.7252	4	2	0.0343
april	85	259	3.1313	0.714	4	2	-0.1188
april	86	250	3.156	0.7139	4	2	-0.0941
april	87	235	3.1745	0.7619	4	2	-0.0756
april	88	244	3.2172	0.6834	4	2	-0.0329
april	89	243	3.1399	0.78	4	2	-0.1102
april	90	245	3.1878	0.7225	4	2	-0.0623
april	91	233	3.4421	0.6548	4	2	0.192
april	92	262	3.2405	0.7108	4	2	-0.0096
april	93	230	3.3304	0.6571	4	2	0.0803
april	94	223	3.1794	0.7254	4	2	-0.0707
april	80-94	3435	3.2501	0.7212	4	2	0
may	80	144	3.0833	0.7526	4	2	-0.0016
may	81	212	3.1226	0.7629	4	2	0.0377
may	82	248	2.9234	0.7729	4	2	-0.1615
may	83	239	3.113	0.7777	4	2	0.0281
may	84	250	3.108	0.7002	4	2	0.0231
may	85	252	3.0873	0.8134	4	2	0.0024
may	86	253	3.17	0.7229	4	2	0.0851
may	87	268	2.9366	0.7691	4	2	-0.1483
may	88	268	2.847	0.7311	4	2	-0.2379
may	89	262	3.3397	0.6573	4	2	0.2548
may	90	250	3.264	0.7406	4	2	0.1791
may	91	246	3.2602	0.8363	4	2	0.1753
may	92	244	3.0574	0.794	4	2	-0.0275
may	93	255	2.9843	0.7528	4	2	-0.1006
may	94	227	2.9912	0.7584	4	2	-0.0937
may	80-94	3618	3.0849	0.7676	4	2	0
june	80	184	3.0163	0.7353	4	2	0.0324
june	81	246	3.122	0.7405	4	2	0.1381
june	82	256	3.1094	0.8283	4	2	0.1255
june	83	241	2.9461	0.8619	4	2	-0.0378
june	84	243	2.716	0.6965	4	2	-0.2679
june	85	260	2.9423	0.7664	4	2	-0.0416
june	86	254	2.9016	0.7183	4	2	-0.0823
june	87	262	3.126	0.7752	4	2	0.1421
june	88	253	2.6957	0.7226	4	2	-0.2882
june	89	263	3.1293	0.8046	4	2	0.1454
june	90	260	2.9577	0.7207	4	2	-0.0262
june	91	263	2.9544	0.7899	4	2	-0.0295
june	92	252	3.2024	0.8051	4	2	0.2185
june	93	267	2.8652	0.6579	4	2	-0.1187
june	94	232	3.0819	0.8412	4	2	0.098
june	80-94	3736	2.9839	0.7784	4	2	0
july	80	209	2.8565	0.7586	4	2	-0.065
july	81	240	2.9583	0.7642	4	2	0.0368
july	82	274	3.0803	0.8304	4	2	0.1588
july	83	273	2.619	0.6485	4	2	-0.3025
july	84	258	3.2481	0.8184	4	2	0.3266
july	85	265	3.0226	0.7974	4	2	0.1011
july	86	255	2.6824	0.6966	4	2	-0.2391
july	87	268	2.7761	0.7307	4	2	-0.1454

july	88	274	2.8723	0.7903	4	2	-0.0492
july	89	272	3.0699	0.8188	4	2	0.1484
july	90	277	3.0505	0.6949	4	2	0.129
july	91	270	2.9889	0.8019	4	2	0.0674
july	92	259	2.9961	0.8093	4	2	0.0746
july	93	277	2.5271	0.6785	4	2	-0.3944
july	94	242	3.095	0.827	4	2	0.1735
july	80-94	3913	2.9215	0.7889	4	2	0
aug	80	269	2.6506	0.6204	4	2	-0.333
aug	81	254	3.1457	0.8236	4	2	0.1621
aug	82	257	3	0.8385	4	2	0.0164
aug	83	245	2.6816	0.7219	4	2	-0.302
aug	84	269	3.0074	0.7629	4	2	0.0238
aug	85	267	3.1461	0.769	4	2	0.1625
aug	86	261	3.1916	0.7297	4	2	0.208
aug	87	269	3.0223	0.7015	4	2	0.0387
aug	88	268	2.8097	0.8286	4	2	-0.1739
aug	89	269	3.197	0.7445	4	2	0.2134
aug	90	278	2.9065	0.8007	4	2	-0.0771
aug	91	266	3.0188	0.8031	4	2	0.0352
aug	92	265	3.1887	0.8085	4	2	0.2051
aug	93	276	2.8659	0.8181	4	2	-0.1177
aug	94	241	2.9129	0.8396	4	2	-0.0707
aug	80-94	3954	2.9836	0.7933	4	2	0
sept	80	244	3.0451	0.8228	4	2	-0.0764
sept	81	251	2.9124	0.7696	4	2	-0.2091
sept	82	257	3.1907	0.728	4	2	0.0692
sept	83	247	3.0648	0.7623	4	2	-0.0567
sept	84	245	3.049	0.745	4	2	-0.0725
sept	85	245	2.9673	0.7179	4	2	-0.1542
sept	86	249	3.3253	0.6858	4	2	0.2038
sept	87	227	3.0132	0.767	4	2	-0.1083
sept	88	241	3.2905	0.6698	4	2	0.169
sept	89	225	3.2933	0.781	4	2	0.1718
sept	90	256	3.0977	0.6819	4	2	-0.0238
sept	91	264	3.0227	0.7292	4	2	-0.0988
sept	92	254	3.2717	0.7339	4	2	0.1502
sept	93	260	3.1731	0.7384	4	2	0.0516
sept	94	229	3.1135	0.7639	4	2	-0.008
sept	80-94	3694	3.1215	0.7491	4	2	0
oct	80	228	3.2632	0.671	4	2	-0.0353
oct	81	215	3.5349	0.5272	4	2	0.2364
oct	82	193	3.285	0.7193	5	2	-0.0135
oct	83	234	3.3376	0.7066	4	2	0.0391
oct	84	257	3.358	0.682	4	2	0.0595
oct	85	190	3.4421	0.6209	4	2	0.1436
oct	86	252	3.2143	0.7097	4	2	-0.0842
oct	87	264	3.1288	0.6573	4	2	-0.1697
oct	88	259	3.332	0.5618	4	2	0.0335
oct	89	253	3.1976	0.6904	4	2	-0.1009
oct	90	252	3.2937	0.6568	4	2	-0.0048
oct	91	275	3.2545	0.6786	4	2	-0.044
oct	92	262	3.1641	0.7056	4	2	-0.1344
oct	93	248	3.3427	0.7362	6	2	0.0442
oct	94	213	3.4319	0.6304	4	2	0.1334
oct	80-94	3595	3.2985	0.674	6	2	0

variable=stagnation parameter

month	year	n	average	std. dev.	maximum	minimum	deviation
april	80	120	0.1583	0.3666	1	0	0.0937
april	81	219	0.0457	0.2092	1	0	-0.0189
april	82	227	0.0352	0.1848	1	0	-0.0294
april	83	220	0.0318	0.1759	1	0	-0.0328
april	84	225	0.0222	0.1477	1	0	-0.0424
april	85	259	0.0965	0.2959	1	0	0.0319
april	86	250	0.088	0.2839	1	0	0.0234
april	87	235	0.0596	0.2372	1	0	-0.005
april	88	244	0.0082	0.0903	1	0	-0.0564
april	89	243	0.107	0.3097	1	0	0.0424
april	90	245	0.0612	0.2402	1	0	-0.0034
april	91	233	0.0944	0.293	1	0	0.0298
april	92	262	0.084	0.2779	1	0	0.0194
april	93	230	0.0609	0.2396	1	0	-0.0037
april	94	223	0.0493	0.217	1	0	-0.0153
april	80-94	3435	0.0646	0.2459	1	0	0
may	80	144	0.0833	0.2774	1	0	-0.0129
may	81	212	0.0802	0.2722	1	0	-0.016
may	82	248	0.1452	0.353	1	0	0.049
may	83	239	0.0962	0.2955	1	0	0
may	84	250	0.076	0.2655	1	0	-0.0202
may	85	252	0.0913	0.2886	1	0	-0.0049
may	86	253	0.0474	0.213	1	0	-0.0488
may	87	268	0.1157	0.3204	1	0	0.0195
may	88	268	0.194	0.3962	1	0	0.0978
may	89	262	0.0649	0.2468	1	0	-0.0313
may	90	250	0.032	0.1764	1	0	-0.0642
may	91	246	0.0691	0.2542	1	0	-0.0271
may	92	244	0.1189	0.3243	1	0	0.0227
may	93	255	0.098	0.298	1	0	0.0018
may	94	227	0.1189	0.3244	1	0	0.0227
may	80-94	3618	0.0962	0.2949	1	0	0
june	80	184	0.1087	0.3121	1	0	-0.0088
june	81	246	0.1301	0.3371	1	0	0.0126
june	82	256	0.1133	0.3176	1	0	-0.0042
june	83	241	0.2116	0.4093	1	0	0.0941
june	84	243	0.2016	0.4021	1	0	0.0841
june	85	260	0.1154	0.3201	1	0	-0.0021
june	86	254	0.0866	0.2818	1	0	-0.0309
june	87	262	0.0763	0.266	1	0	-0.0412
june	88	253	0.1897	0.3929	1	0	0.0722
june	89	263	0.1141	0.3185	1	0	-0.0034
june	90	260	0.1	0.3006	1	0	-0.0175
june	91	263	0.1103	0.3138	1	0	-0.0072
june	92	252	0.0238	0.1528	1	0	-0.0937
june	93	267	0.0899	0.2866	1	0	-0.0276
june	94	232	0.0991	0.2995	1	0	-0.0184
june	80-94	3736	0.1175	0.3221	1	0	0
july	80	209	0.1435	0.3515	1	0	-0.0032
july	81	240	0.0958	0.295	1	0	-0.0509
july	82	274	0.1606	0.3678	1	0	0.0139
july	83	273	0.304	0.4608	1	0	0.1573
july	84	258	0.0969	0.2964	1	0	-0.0498
july	85	265	0.0943	0.2929	1	0	-0.0524
july	86	255	0.1216	0.3274	1	0	-0.0251
july	87	268	0.25	0.4338	1	0	0 1033

july	88	274	0.1861	0.3899	1	0	0.0394
july	89	272	0.1949	0.3968	1	0	0.0482
july	90	277	0.0686	0.2532	1	0	-0.0781
july	91	270	0.0852	0.2797	1	0	-0.0615
july	92	259	0.0965	0.2959	1	0	-0.0502
july	93	277	0.1877	0.3912	1	0	0.041
july	94	242	0.095	0.2939	1	0	-0.0517
july	80-94	3913	0.1467	0.3538	1	0	0
aug	80	269	0.197	0.3985	1	0	0.0033
aug	81	254	0.1772	0.3826	1	0	-0.0165
aug	82	257	0.2529	0.4355	1	0	0.0592
aug	83	245	0.3061	0.4618	1	0	0.1124
aug	84	269	0.197	0.3985	1	0	0.0033
aug	85	267	0.206	0.4052	1	0	0.0123
aug	86	261	0.0536	0.2257	1	0	-0.1401
aug	87	269	0.145	0.3527	1	0	-0.0487
aug	88	268	0.2239	0.4176	1	0	0.0302
aug	89	269	0.2082	0.4068	1	0	0.0145
aug	90	278	0.205	0.4045	1	0	0.0113
aug	91	266	0.1805	0.3853	1	0	-0.0132
aug	92	265	0.1208	0.3265	1	0	-0.0729
aug	93	276	0.2283	0.4205	1	0	0.0346
aug	94	241	0.2116	0.4093	1	0	0.0179
aug	80-94	3954	0.1937	0.3953	1	0	0
sept	80	244	0.1557	0.3634	1	0	-0.066
sept	81	251	0.3984	0.4905	1	0	0.1767
sept	82	257	0.2374	0.4263	1	0	0.0157
sept	83	247	0.2834	0.4516	1	0	0.0617
sept	84	245	0.2082	0.4068	1	0	-0.0135
sept	85	245	0.2939	0.4565	1	0	0.0722
sept	86	249	0.1727	0.3787	1	0	-0.049
sept	87	227	0.2379	0.4267	1	0	0.0162
sept	88	241	0.1992	0.4002	1	0	-0.0225
sept	89	225	0.1733	0.3794	1	0	-0.0484
sept	90	256	0.2344	0.4244	1	0	0.0127
sept	91	264	0.322	0.4681	1	0	0.1003
sept	92	254	0.0748	0.2636	1	0	-0.1469
sept	93	260	0.1231	0.3292	1	0	-0.0986
sept	94	229	0.2052	0.4048	1	0	-0.0165
sept	80-94	3694	0.2217	0.4155	1	0	0
oct	80	228	0.2237	0.4176	1	0	0.0206
oct	81	215	0.1023	0.3038	1	0	-0.1008
oct	82	193	0.228	0.4206	1	0	0.0249
oct	83	234	0.2222	0.4166	1	0	0.0191
oct	84	257	0.2296	0.4214	1	0	0.0265
oct	85	190	0.1211	0.3271	1	0	-0.082
oct	86	252	0.2421	0.4292	1	0	0.039
oct	87	264	0.2955	0.4571	1	0	0.0924
oct	88	259	0.1429	0.3506	1	0	-0.0602
oct	89	253	0.2253	0.4186	1	0	0.0222
oct	90	252	0.2421	0.4292	1	0	0.039
oct	91	275	0.2218	0.4162	1	0	0.0187
oct	92	262	0.1908	0.3937	1	0	-0.0123
oct	93	248	0.1815	0.3862	1	0	-0.0216
oct	94	213	0.1362	0.3438	1	0	-0.0669
oct	80-94	3595	0.2031	0.4023	1	0	0

variable=stagnation events

month	year	n	average	std. dev.	maximum	minimum	deviation
april	80	120	0.025	0.1568	1	0	0.0235
april	81	219	0	0	0	0	-0.0015
april	82	227	0	0	0	0	-0.0015
april	83	220	0	0	0	0	-0.0015
april	84	225	0	0	0	0	-0.0015
april	85	259	0	0	0	0	-0.0015
april	86	250	0.009	0.101	1.25	0	0.0075
april	87	235	0	0	0	0	-0.0015
april	88	244	0	0	0	0	-0.0015
april	89	243	0	0	0	0	-0.0015
april	90	245	0	0	0	0	-0.0015
april	91	233	0	0	0	0	-0.0015
april	92	262	0	0	0	0	-0.0015
april	93	230	0	0	0	0	-0.0015
april	94	223	0	0	0	0	-0.0015
april	80-94	3435	0.0015	0.0402	1.25	0	0
may	80	144	0	0	0	0	-0.0028
may	81	212	0	0	0	0	-0.0028
may	82	248	0.004	0.0635	1	0	0.0012
may	83	239	0	0	0	0	-0.0028
may	84	250	0	0	0	0	-0.0028
may	85	252	0	0	0	0	-0.0028
may	86	253	0	0	0	0	-0.0028
may	87	268	0	0	0	0	-0.0028
may	88	268	0.0168	0.1375	1.25	0	0.014
may	89	262	0	0	0	0	-0.0028
may	90	250	0	0	0	0	-0.0028
may	91	246	0	0	0	0	-0.0028
may	92	244	0	0	0	0	-0.0028
may	93	255	0	0	0	0	-0.0028
may	94	227	0.0198	0.1493	1.25	0	0.017
may	80-94	3618	0.0028	0.0557	1.25	0	0
june	80	184	0	0	0	0	-0.0031
june	81	246	0	0	0	0	-0.0031
june	82	256	0	0	0	0	-0.0031
june	83	241	0.0353	0.2099	1.75	0	0.0322
june	84	243	0	0	0	0	-0.0031
june	85	260	0	0	0	0	-0.0031
june	86	254	0	0	0	0	-0.0031
june	87	262	0	0	0	0	-0.0031
june	88	253	0.0128	0.1182	1.25	0	0.0097
june	89	263	0	0	0	0	-0.0031
june	90	260	0	0	0	0	-0.0031
june	91	263	0	0	0	0	-0.0031
june	92	252	0	0	0	0	-0.0031
june	93	267	0	0	0	0	-0.0031
june	94	232	0	0	0	0	-0.0031
june	80-94	3736	0.0031	0.0621	1.75	0	0
july	80	209	0	0	0	0	-0.0156
july	81	240	0	0	0	0	-0.0156
july	82	274	0.0164	0.136	1.25	0	0.0008
july	83	273	0.0192	0.1417	1.25	0	0.0036
july	84	258	0	0	0	0	-0.0156
july	85	265	0	0	0	0	-0.0156
july	86	255	0.0118	0.108	1	0	-0.0038
july	87	268	0.1371	0.4647	2.25	0	0.1215

july	88	274	0	0	0	0	-0.0156
july	89	272	0.0248	0.1666	1.25	0	0.0092
july	90	277	0	0	0	0	-0.0156
july	91	270	0.0037	0.0609	1	0	-0.0119
july	92	259	0	0	0	0	-0.0156
july	93	277	0.0135	0.1313	1.5	0	-0.0021
july	94	242	0	0	0	0	-0.0156
july	80-94	3913	0.0156	0.1508	2.25	0	0
aug	80	269	0.04	0.2061	1.5	0	0.0317
aug	81	254	0	0	0	0	-0.0083
aug	82	257	0	0	0	0	-0.0083
aug	83	245	0	0	0	0	-0.0083
aug	84	269	0.0112	0.1052	1	0	0.0029
aug	85	267	0.0112	0.1056	1	0	0.0029
aug	86	261	0	0	0	0	-0.0083
aug	87	269	0	0	0	0	-0.0083
aug	88	268	0.042	0.215	1.25	0	0.0337
aug	89	269	0.0149	0.1213	1	0	0.0066
aug	90	278	0	0	0	0	-0.0083
aug	91	266	0	0	0	0	-0.0083
aug	92	265	0	0	0	0	-0.0083
aug	93	276	0.0036	0.0602	1	0	-0.0047
aug	94	241	0	0	0	0	-0.0083
aug	80-94	3954	0.0083	0.0946	1.5	0	0
sept	80	244	0.0041	0.064	1	0	-0.0105
sept	81	251	0.0986	0.3442	1.75	0	0.084
sept	82	257	0.0039	0.0624	1	0	-0.0107
sept	83	247	0.0273	0.1746	1.25	0	0.0127
sept	84	245	0.0122	0.1102	1	0	-0.0024
sept	85	245	0	0	0	0	-0.0146
sept	86	249	0.008	0.0894	1	0	-0.0066
sept	87	227	0.0176	0.1319	1	0	0.003
sept	88	241	0	0	0	0	-0.0146
sept	89	225	0	0	0	0	-0.0146
sept	90	256	0	0	0	0	-0.0146
sept	91	264	0.0208	0.1512	1.25	0	0.0062
sept	92	254	0	0	0	0	-0.0146
sept	93	260	0.0048	0.0775	1.25	0	-0.0098
sept	94	229	0.0197	0.1486	1.25	0	0.0051
sept	80-94	3694	0.0146	0.1304	1.75	0	0
oct	80	228	0.0132	0.1142	1	0	0.0012
oct	81	215	0	0	0	0	-0.012
oct	82	193	0.0389	0.202	1.25	0	0.0269
oct	83	234	0.0331	0.1902	1.25	0	0.0211
oct	84	257	0	0	0	0	-0.012
oct	85	190	0	0	0	0	-0.012
oct	86	252	0.0298	0.1935	1.5	0	0.0178
oct	87	264	0.0152	0.1224	1	0	0.0032
oct	88	259	0	0	0	0	-0.012
oct	89	253	0.0178	0.1415	1.25	0	0.0058
oct	90	252	0.004	0.063	1	0	-0.008
oct	91	275	0.0282	0.1771	1.5	0	0.0162
oct	92	262	0	0	0	0	-0.012
oct	93	248	0	0	0	0	-0.012
oct	94	213	0	0	0	0	-0.012
oct	80-94	3595	0.012	0.1154	1.5	0	0

variable=stagnation count

month	year	n	average	std. dev.	maximum	minimum	
april	80	120	0.3167	0.8598	4	0	0.2346
april	81	219	0.0457	0.2092	1	0	-0.0364
april	82	227	0.0352	0.1848	1	0	-0.0469
april	83	220	0.0364	0.2106	2	0	-0.0457
april	84	225	0.0222	0.1477	1	0	-0.0599
april	85	259	0.1081	0.3465	2	0	0.026
april	86	250	0.14	0.56	5	0	0.0579
april	87	235	0.0936	0.4131	3	0	0.0115
april	88	244	0.0082	0.0903	1	0	-0.0739
april	89	243	0.1193	0.361	2	0	0.0372
april	90	245	0.0776	0.3234	2	0	-0.0045
april	91	233	0.103	0.3317	2	0	0.0209
april	92	262	0.0954	0.3311	2	0	0.0133
april	93	230	0.0696	0.2872	2	0	-0.0125
april	94	223	0.0583	0.2705	2	0	-0.0238
april	80-94	3435	0.0821	0.3534	5	0	0
may	80	144	0.1042	0.3872	3	0	-0.0274
may	81	212	0.1132	0.4315	3	0	-0.0184
may	82	248	0.1976	0.5448	4	0	0.066
may	83	239	0.1381	0.4783	3	0	0.0065
may	84	250	0.092	0.3406	2	0	-0.0396
may	85	252	0.0952	0.3074	2	0	-0.0364
may	86	253	0.0474	0.213	1	0	-0.0842
may	87	268	0.1269	0.3656	2	0	-0.0047
may	88	268	0.3209	0.8036	5	0	0.1893
may	89	262	0.0687	0.2681	2	0	-0.0629
may	90	250	0.032	0.1764	1	0	-0.0996
may	91	246	0.0691	0.2542	1	0	-0.0625
may	92	244	0.1639	0.4777	2	0	0.0323
may	93	255	0.1412	0.4816	3	0	0.0096
may	94	227	0.2511	0.8056	5	0	0.1195
may	80-94	3618	0.1316	0.466	5	0	0
june	80	184	0.1467	0.4619	3	0	-0.0134
june	81	246	0.187	0.5473	3	0	0.0269
june	82	256	0.1211	0.35	2	0	-0.039
june	83	241	0.4066	1.0127	7	0	0.2465
june	84	243	0.2634	0.5861	3	0	0.1033
june	85	260	0.1231	0.3518	2	0	-0.037
june	86	254	0.1181	0.4285	3	0	-0.042
june	87	262	0.0878	0.3215	2	0	-0.0723
june	88	253	0.332	0.8119	5	0	0.1719
june	89	263	0.1331	0.402	3	0	-0.027
june	90	260	0.1192	0.3795	2	0	-0.0409
june	91	263	0.1521	0.4782	3	0	-0.008
june	92	252	0.0238	0.1528	1	0	-0.1363
june	93	267	0.0899	0.2866	1	0	-0.0702
june	94	232	0.1164	0.3714	2	0	-0.0437
june	80-94	3736	0.1601	0.5118	7	0	0
july	80	209	0.1675	0.4338	2	0	-0.0809
july	81	240	0.1083	0.3494	2	0	-0.1401
july	82	274	0.2701	0.7656	5	0	0.0217
july	83	273	0.5165	0.9397	5	0	0.2681
july	84	258	0.1202	0.3909	2	0	-0.1282
july	85	265	0.1283	0.4423	3	0	-0.1201
july	86	255	0.2078	0.664	4	0	-0.0406
july	87	268	0.8097	1.9014	9	0	0.5613

july	88	274	0.2701	0.6348	3	0	0.0217
july	89	272	0.3419	0.8617	5	0	0.0935
july	90	277	0.0903	0.3747	3	0	-0.1581
july	91	270	0.1259	0.4867	4	0	-0.1225
july	92	259	0.1158	0.3763	2	0	-0.1326
july	93	277	0.2599	0.6949	6	0	0.0115
july	94	242	0.1364	0.4667	3	0	-0.112
july	80-94	3913	0.2484	0.7853	9	0	0
aug	80	269	0.4349	1.0476	6	0	0.1362
aug	81	254	0.2323	0.5455	3	0	-0.0664
aug	82	257	0.3658	0.7061	3	0	0.0671
aug	83	245	0.4694	0.8073	3	0	0.1707
aug	84	269	0.3086	0.7315	4	0	0.0099
aug	85	267	0.3596	0.8168	4	0	0.0609
aug	86	261	0.0536	0.2257	1	0	-0.2451
aug	87	269	0.1524	0.3803	2	0	-0.1463
aug	88	268	0.4664	1.0612	5	0	0.1677
aug	89	269	0.342	0.7835	4	0	0.0433
aug	90	278	0.2698	0.5849	3	0	-0.0289
aug	91	266	0.203	0.4557	2	0	-0.0957
aug	92	265	0.1509	0.435	2	0	-0.1478
aug	93	276	0.3478	0.7302	4	0	0.0491
aug	94	241	0.332	0.7287	3	0	0.0333
aug	80-94	3954	0.2987	0.7152	6	0	0
sept	80	244	0.2418	0.6502	4	0	-0.1385
sept	81	251	0.9363	1.5139	7	0	0.556
sept	82	257	0.3813	0.7822	4	0	0.001
sept	83	247	0.5263	1.0233	5	0	0.146
sept	84	245	0.3633	0.8215	4	0	-0.017
sept	85	245	0.4571	0.8168	3	0	0.0768
sept	86	249	0.241	0.6207	4	0	-0.1393
sept	87	227	0.4317	0.9113	4	0	0.0514
sept	88	241	0.2863	0.6431	3	0	-0.094
sept	89	225	0.2667	0.6614	3	0	-0.1136
sept	90	256	0.3242	0.6511	3	0	-0.0561
sept	91	264	0.5833	1.021	5	0	0.203
sept	92	254	0.1339	0.5314	3	0	-0.2464
sept	93	260	0.1692	0.5293	5	0	-0.2111
sept	94	229	0.3493	0.8378	5	0	-0.031
sept	80-94	3694	0.3803	0.8586	7	0	0
oct	80	228	0.3465	0.7672	4	0	0.0205
oct	81	215	0.1349	0.4382	3	0	-0.1911
oct	82	193	0.4663	1.0409	5	0	0.1403
oct	83	234	0.453	1.0233	5	0	0.127
oct	84	257	0.3502	0.7248	3	0	0.0242
oct	85	190	0.1526	0.4399	2	0	-0.1734
oct	86	252	0.4603	1.0306	6	0	0.1343
oct	87	264	0.4735	0.8803	4	0	0.1475
oct	88	259	0.2046	0.5711	3	0	-0.1214
oct	89	253	0.3834	0.8679	5	0	0.0574
oct	90	252	0.3571	0.7248	4	0	0.0311
oct	91	275	0.3964	0.9237	6	0	0.0704
oct	92	262	0.2557	0.5868	3	0	-0.0703
oct	93	248	0.2258	0.5299	3	0	-0.1002
oct	94	213	0.169	0.4551	2	0	-0.157
oct	80-94	3595	0.326	0.7749	6	0	0